

Critical Design Review

JSC-Houston, 13-16 May 2003

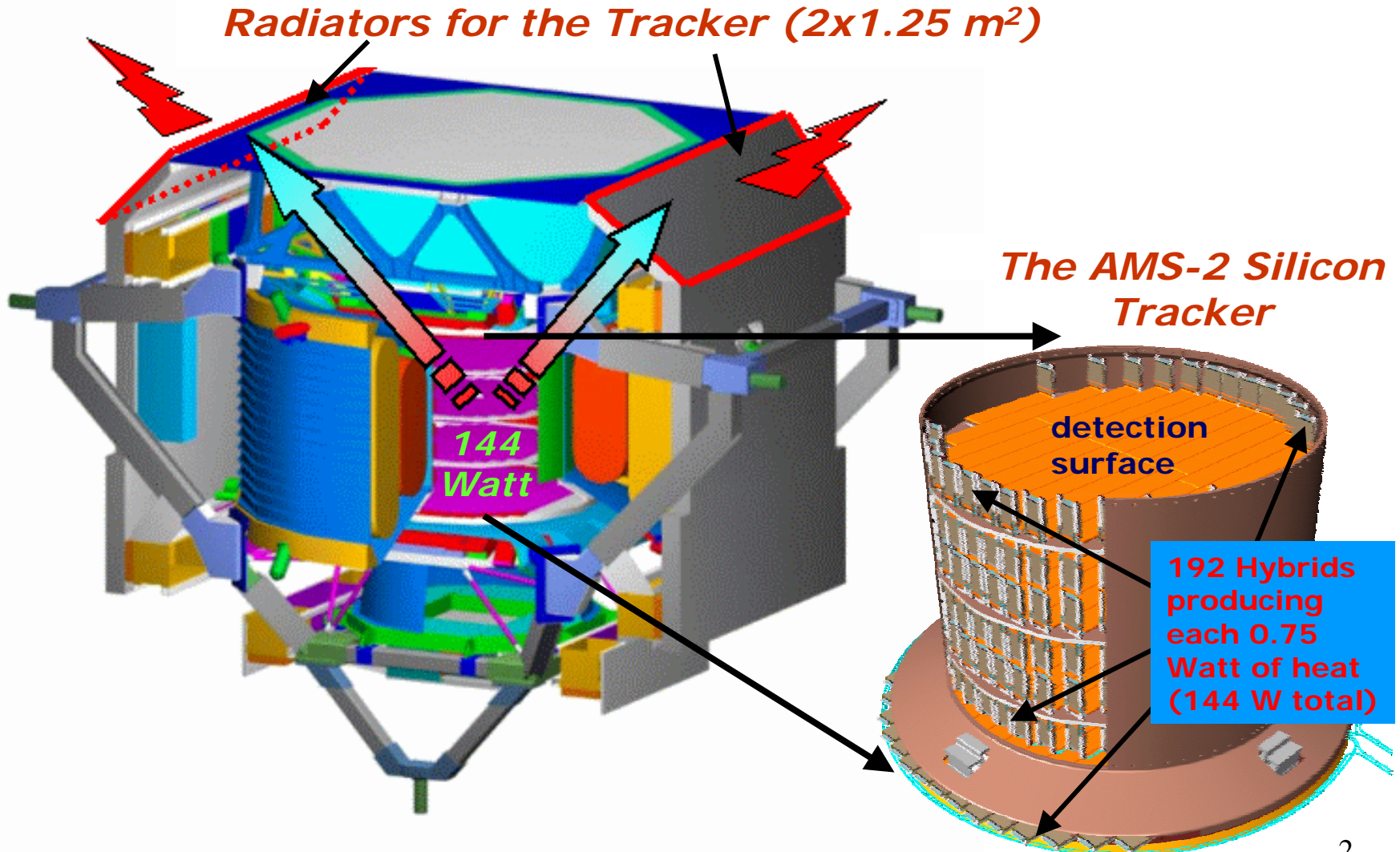
AMS Tracker Thermal Control System (TTCS)

CDR Data Package

Bart Verlaat (NIKHEF)

Ad Delil, Aswin Pauw, Gerrit van Donk & Arend Woering (NLR)





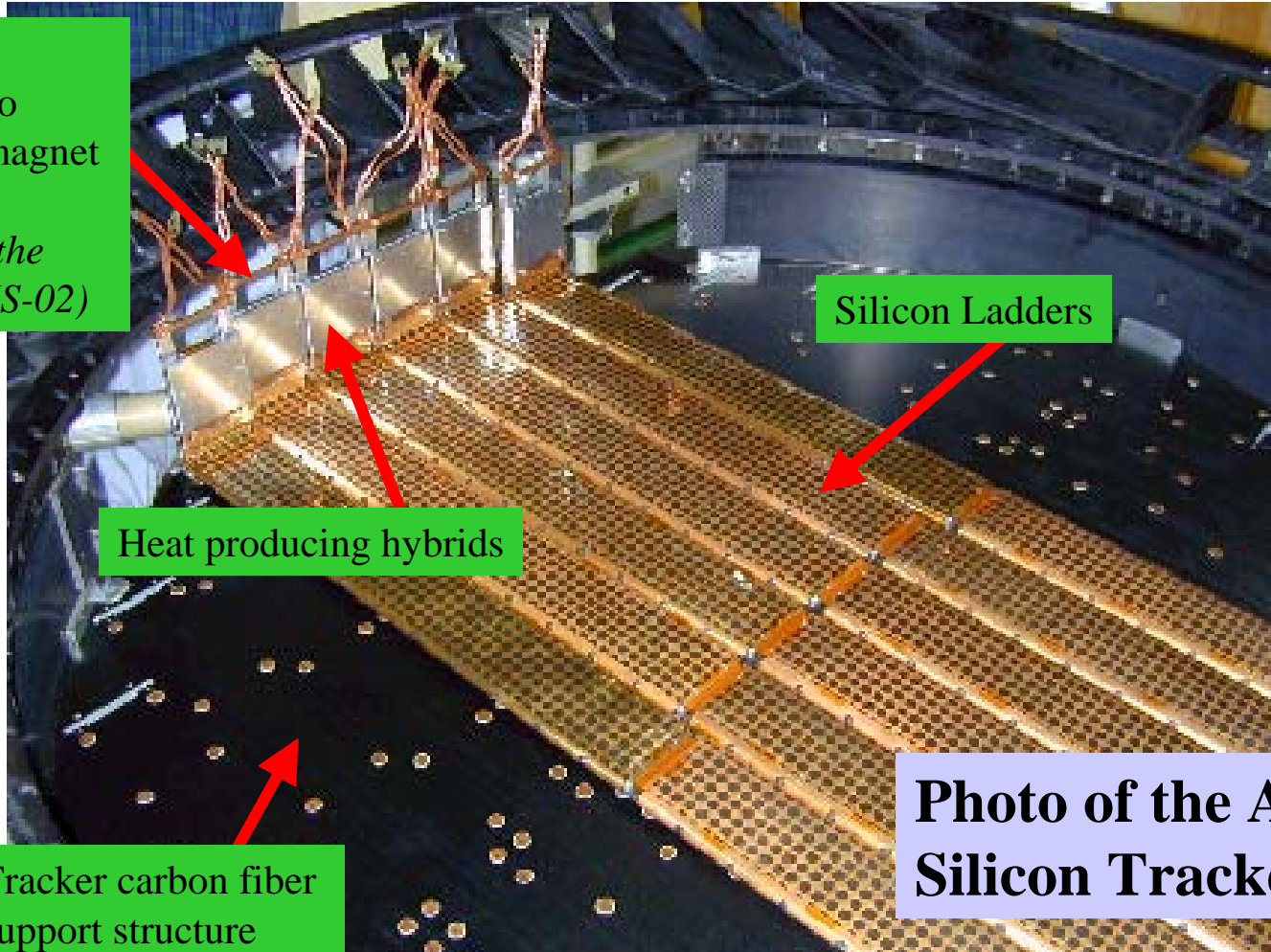
Thermal bar
connection to
permanent magnet
(Will be the
interface to the
TTCS in AMS-02)

Silicon Ladders

Heat producing hybrids

Tracker carbon fiber
support structure

Photo of the AMS-1
Silicon Tracker



AMS-Silicon Tracker Thermal Requirements

Silicon wafer thermal requirements:

- Operating temperature:
-10 °C / +25 °C
- Survival temperature:
-20 °C / +40 °C
- Temperature stability:
3 °C per orbit
- Maximum accepted gradient between any silicon:
10.0 °C
- Dissipated heat:
2.0 Watt EOL

Hybrid circuit thermal requirements:

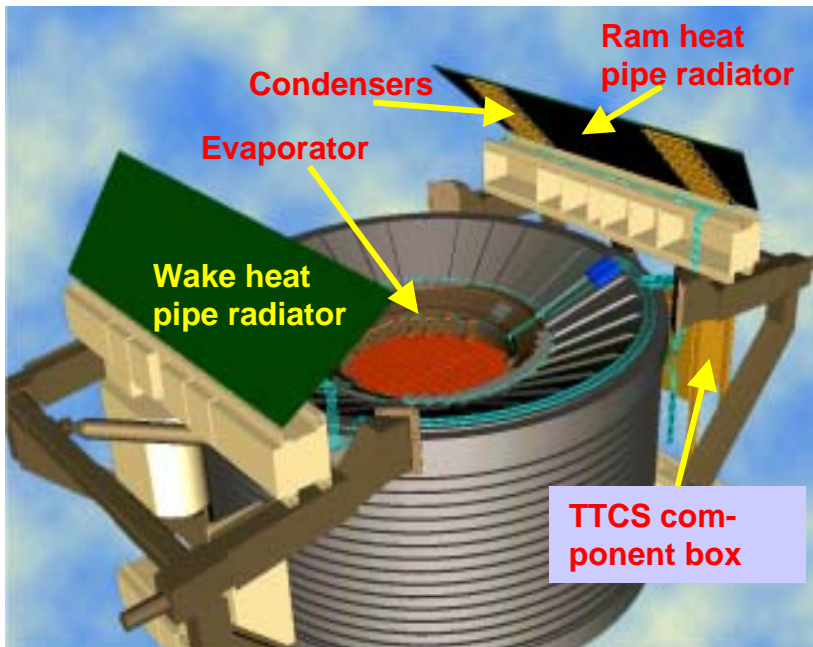
- Operating temperature:
-10 °C / +40 °C
- Survival temperature:
-20 °C / +60 °C
- Dissipated heat:
**144 W total ($\pm 10\%$),
0.75 W per hybrid pair
($S=0.47$ W, $K=0.28$ W)**

Star Tracker thermal requirements:

- Operating temperature:
-30 °C / 40 °C
- Survival temperature:
-40 °C / 100 °C
- Dissipated heat:
6.8 W total, 3.4 W per ASTS

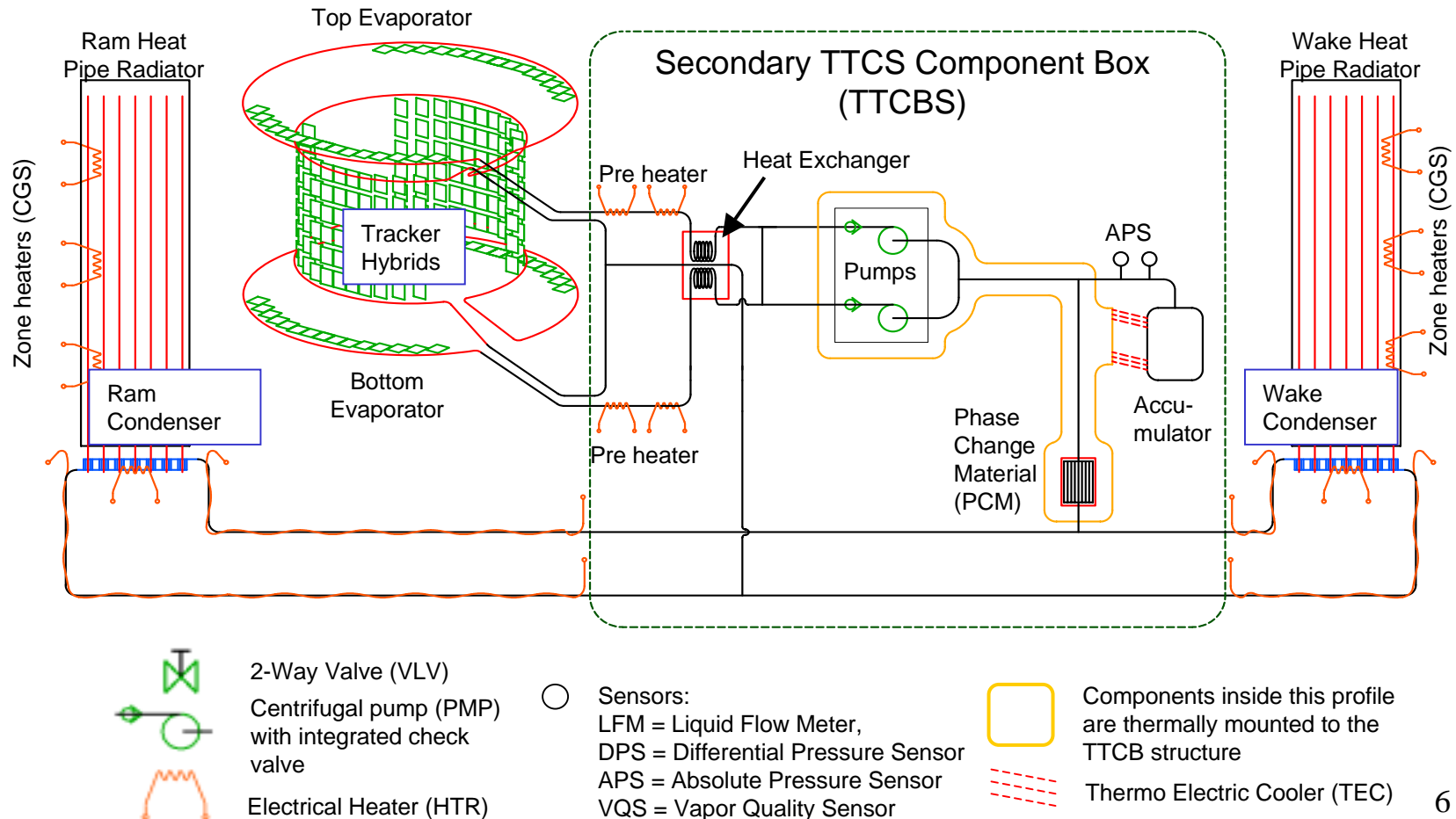
AMS-Tracker Thermal Control System (TTCS)

(A mechanically pumped CO₂-Loop)

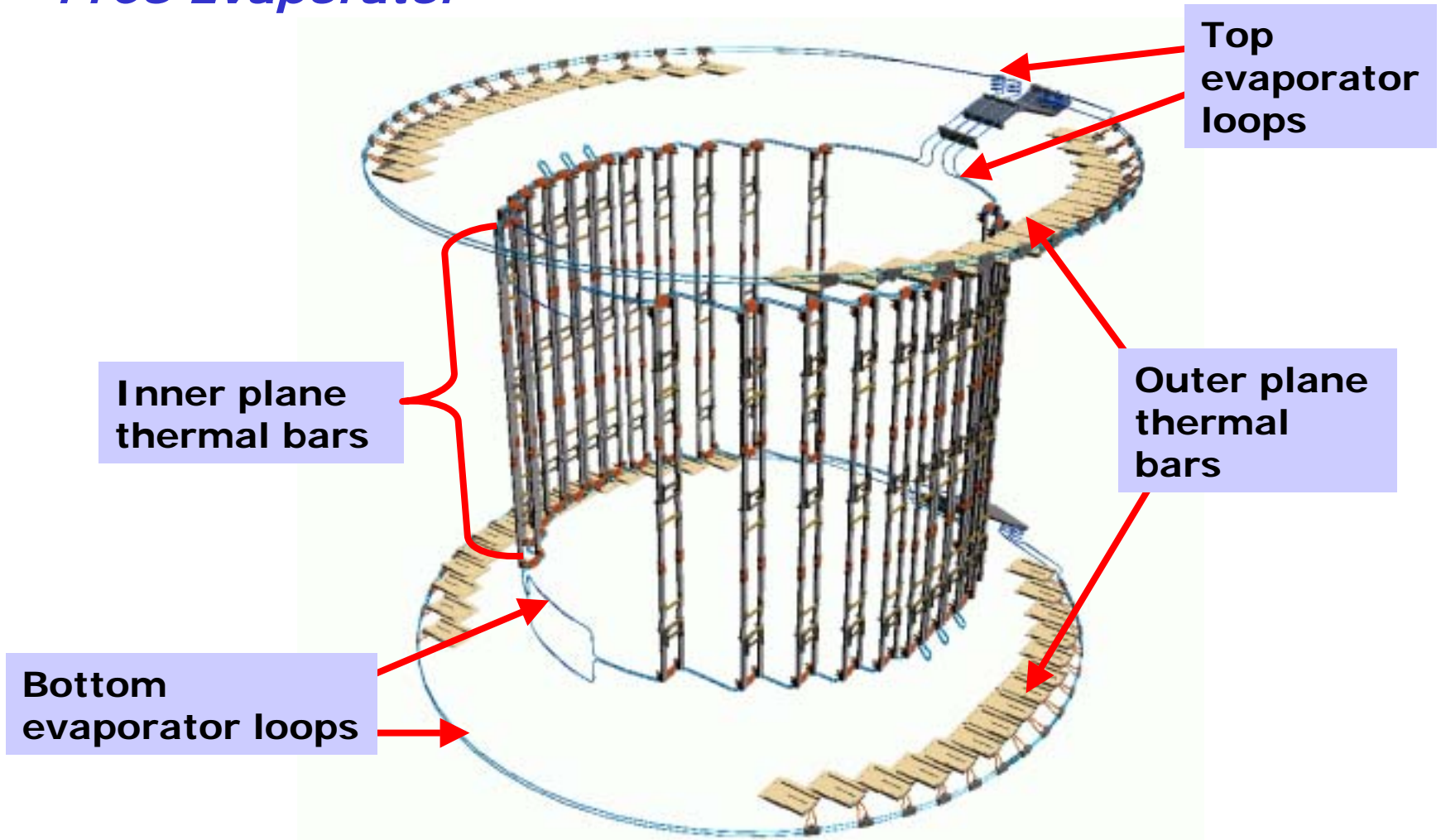


- The Tracker Thermal Control System (TTCS) is a system to control the temperature of the AMS-Tracker within a 10 °C gradient inside the Tracker and an over orbit stability better than 3 °C.
- The system uses carbon dioxide (CO₂/R744) as working fluid. The 144 Watt heat dissipation inside the Tracker is absorbed by the CO₂ using the latent heat of evaporation.
- The fluid is being circulated using a centrifugal pump
- The evaporator temperature is maintained constant over orbit by a peltier controlled accumulator vessel. The evaporator temperature can be set between -15 °C and +15 °C.
- The total heat (Tracker + TTCS) is rejected to space by 2 opposite facing radiators (ram and wake). The radiators are out of phase to damp the incoming orbital flux excursions to a minimum.
- The TTCS will also take care of the thermal control of the Amiga Star Tracker System.

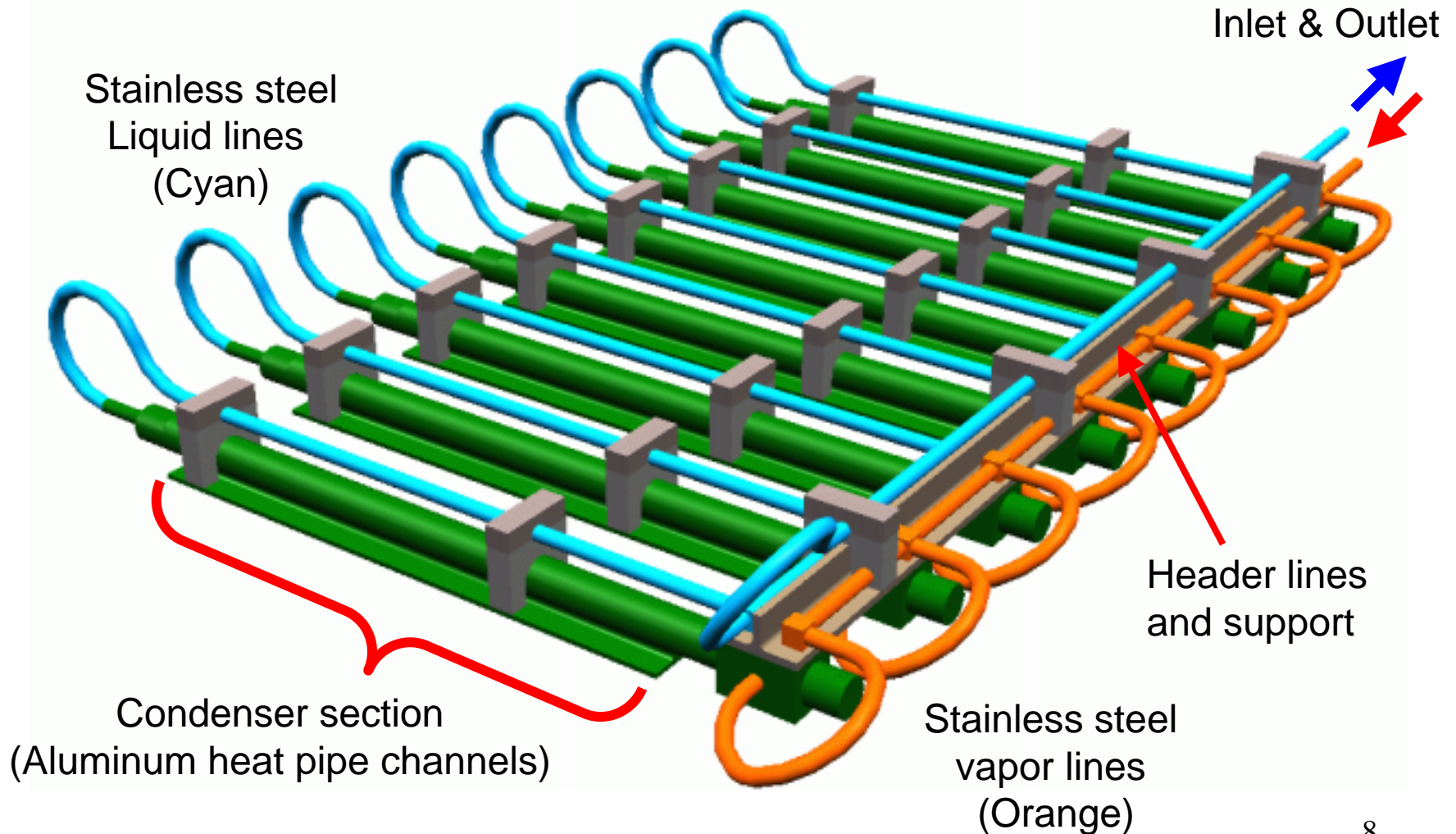
Secondary TTCS (TTCSS)



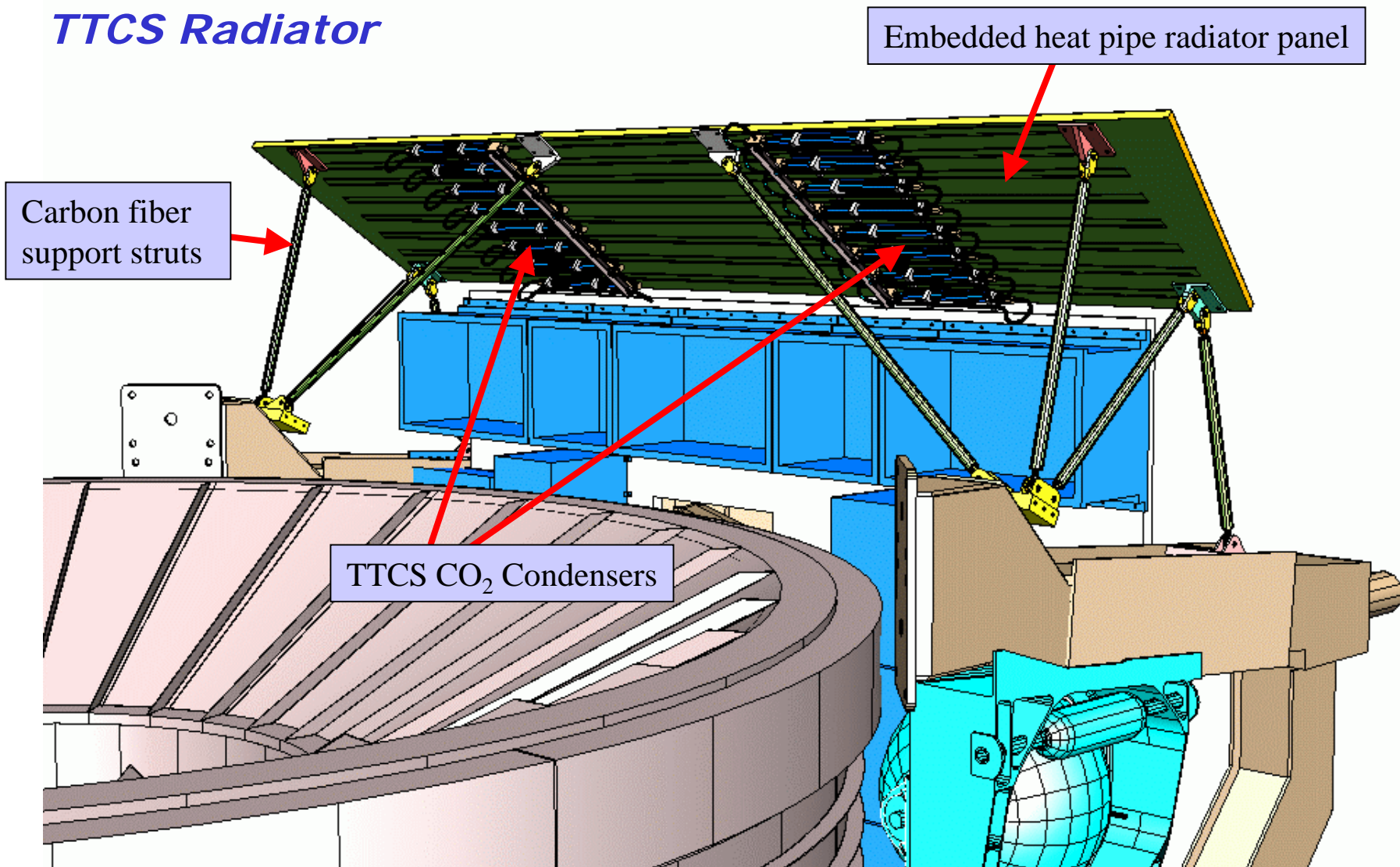
TTCS Evaporator



TTCS Condenser



TTCS Radiator



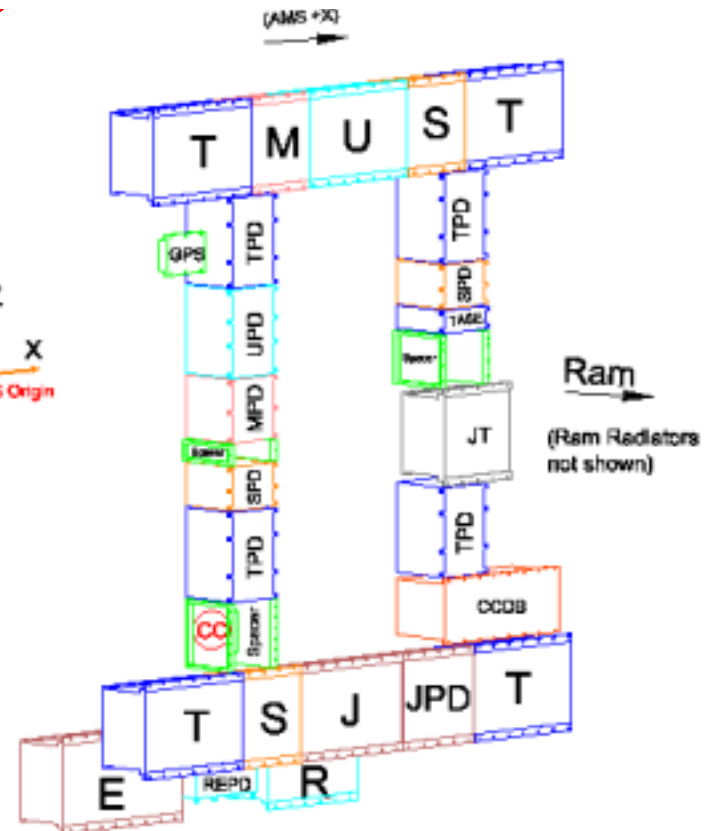
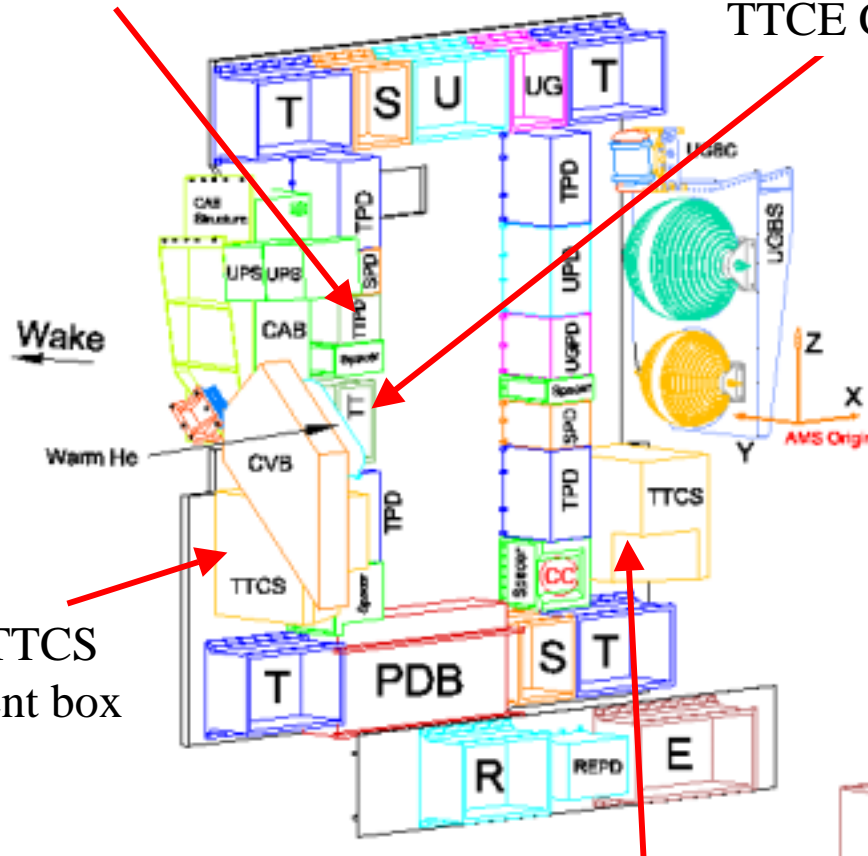
TTCS Control Hardware Location

TTPD Power Distribution Box

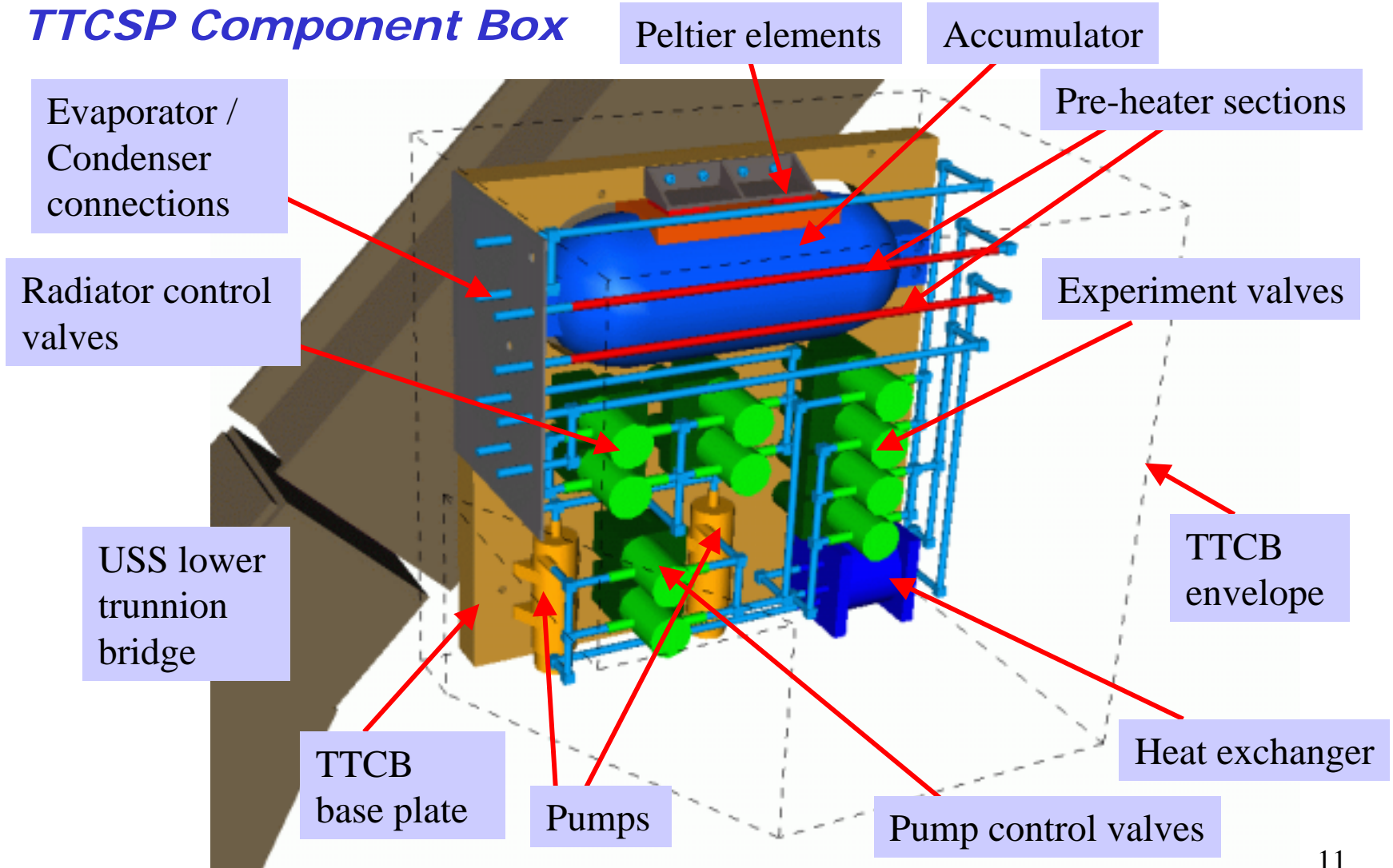
TTCE Control Electronics Box

Primary TTCS
Component box

Secondary TTCS
Component Box

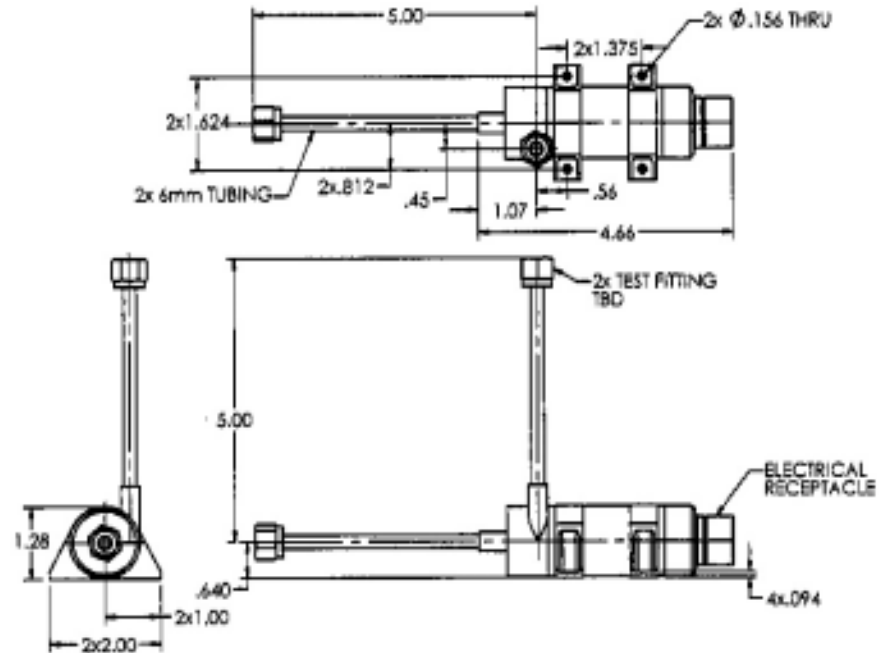
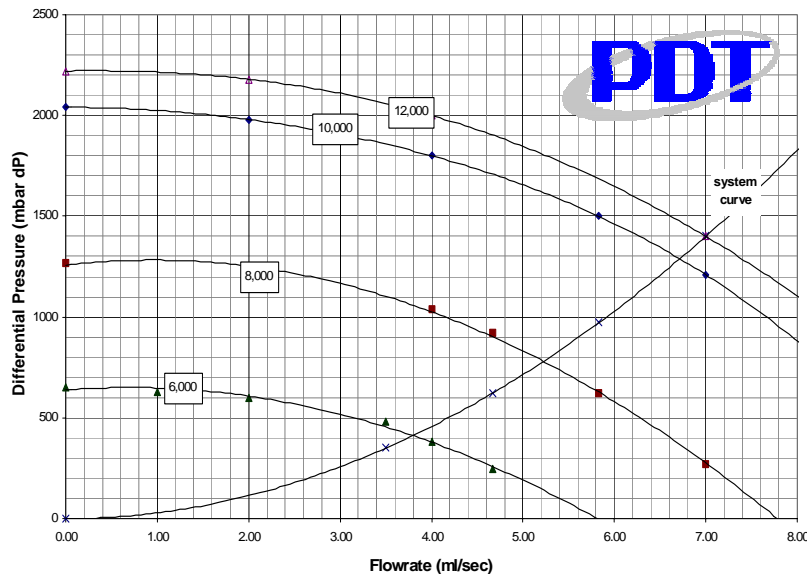


TTCS Component Box



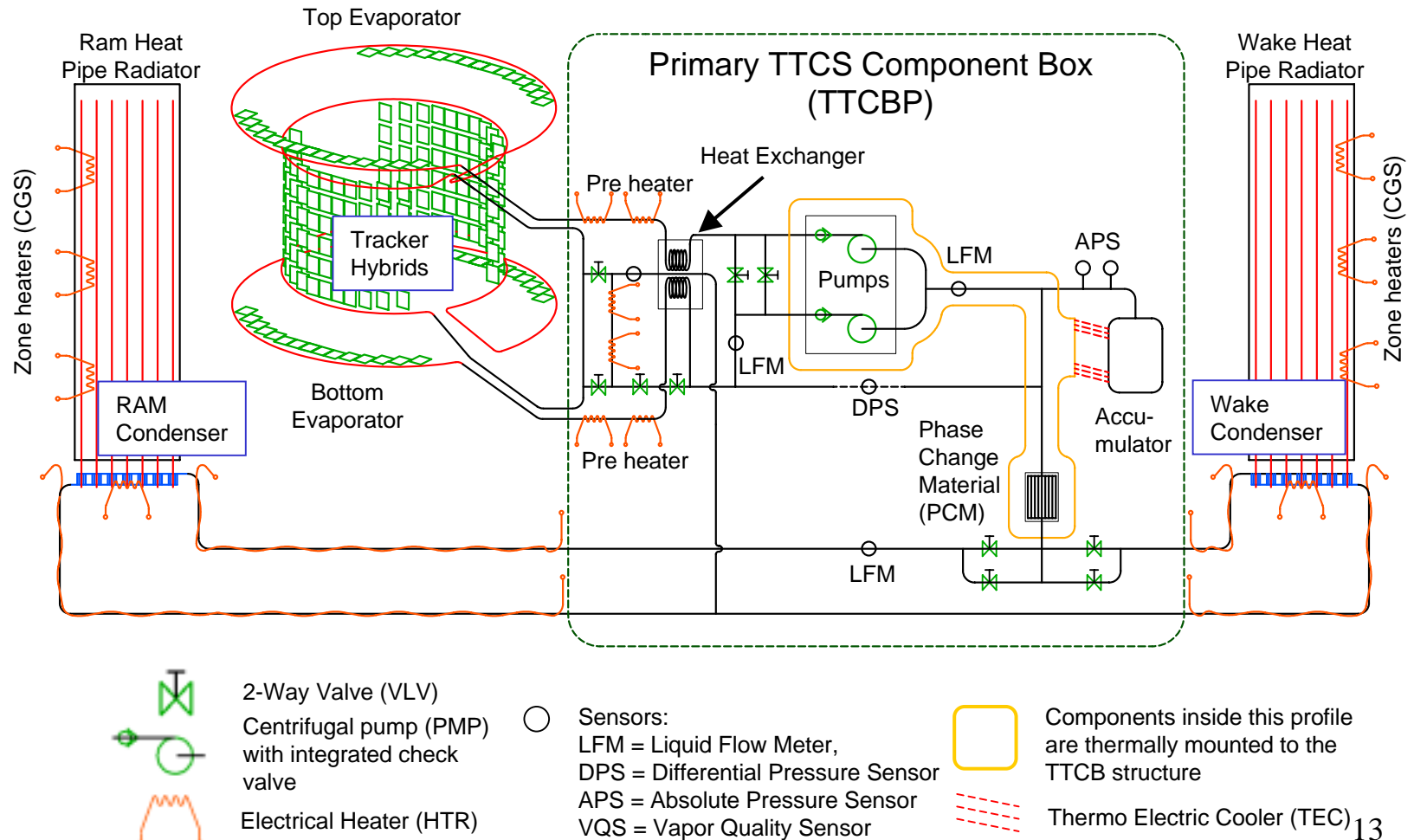
TTCS Circulation pump

PDT Model 5059-1
Two Stage Centrifugal CO₂ Pump
Calculated Performance
28 Vdc, Inlet Pressure = 10 psi above Sat. Liq.



- Pacific Design Technologies (PDT) in Goleta(Ca) has been contracted to develop the TTCS pumps.
- The TTCS pump will be a modified Mars Pathfinder centrifugal pump, optimized for the TTCS flow- and differential- and system pressure range, but with the reliability of the proven Pathfinder pump, which has operated successfully during the mission to Mars.

Primary TTCS (TTCS_P)



TTCSP Overview

- *All thermal experiment hardware in the TTCSP.*
- *Valves to create experimental cases and thermal control cases*
- *Different evaporator concepts possible owing to valves.*
 - *Parallel operated evaporators*
 - *1 pump per evaporator*
 - *Serial operated evaporators*
 - *Evaporator by-pass for thermal experiments*
- *Condenser optimization*
 - *Too cold or too warm condensers can be closed or restricted by valves*
- *Valves are redundant such that in case of a single failure the TTCSP is still functioning at a level better than the secondary TTCS (Which has no actuators other than the pumps). Only experimental or optimization cases are affected.*
- *A PCM (Phase Change Material) is foreseen to damp the orbital load. (Hot solar peak buffering)*

TTCSP Component overview

Inside TTCBP

- *2x Pump (PDT Model 5059-1; 2-Stage centrifugal pump with integrated check valves)*
- *10x Proportional two-way valves (Bradford Engineering)*
- *1x Accumulator (1.3 Liter), (Self engineered)*
- *1x Phase change material (A melting/freezing paraffin buffer, Supplier Esli)*
- *1x Three volume heat-exchanger (Self engineered)*
- *2x Peltier elements (Supplier: Melcor)*
- *3x Liquid flow meter (Via Differential pressure using Keller DPS sensors)*
- *2x Absolute pressure sensor (Supplier: Keller)*
- *1x Differential pressure sensor (Supplier: Keller)*
- *TBDx Dallas temperature sensors (Dallas DS18S20/TO92)*
- *TBDx PT100(0) temperature sensors (Supplier TBD)*
- *10x Electrical shielded resistance wire heaters (Supplier: Thermacoax)*

Outside TTCBP

- *2x Evaporator assemblies (Self engineered)*
(Evaporator is qua design the only common shared hardware between the primary and the secondary TTCS)
- *2x Condenser (Self engineered)*
- *Thermal control electronics in TTCE crate on wake radiator (Self engineered)*

TTCSS Overview (Schematic layout is shown on page 6)

- *No experimental hardware in the TTCSS.*
- *No actuated valves*
- *1 evaporator concept possible:*
 - *Parallel operated evaporators only*
- *No Condenser optimization possible.*
- *Due to the absence of control valves the secondary TTCS will show a worse thermal performance than the primary. (More pre-heat power)*
- *The secondary is simpler (No active components other than the pumps) thus more reliable than the primary TTCS.*
- *No sensors (other than the APS) are in the pressurized volume.*
- *A PCM (Phase Change Material) is foreseen to dampen the orbital load (Hot solar peak buffering).*

TTCSS Component Overview

Inside TTCBS:

- *2x Pump (PDT Model 5059-1; 2-Stage centrifugal pump with integrated check valves)*
- *1x Accumulator (1.3 Liter), (Self engineered)*
- *1x Phase change material (A melting/freezing paraffin buffer, Supplier Esli)*
- *1x Three volume heat-exchanger (Self engineered)*
- *2x Peltier elements (Supplier: Melcor)*
- *2x Absolute pressure sensor (Supplier: Keller)*
- *TBDx Dallas temperature sensors (Dallas DS18S20/TO92)*
- *TBDx PT100(0) temperature sensors (Supplier TBD)*
- *10x Electrical shielded resistance wire heaters (Supplier: Thermacoax)*

Outside TTCBS:

- *2x Evaporator assemblies (Self engineered)*
(Evaporator is qua design the only common shared hardware between the primary and the secondary TTCS)
- *2x Condenser (Self engineered)*
- *Thermal control electronics in TTCE crate on wake radiator (Self engineered)*

TTCS Main material and construction overview

General materials

- *Tubes: CRES 316L*
- *Evaporator bridges :OFHC Copper*
- *Condenser profiles: AA 6061*
- *Refrigerant: CO₂ (R744)*
- *Bolts: CRES A286 (#10 and above) and CRES 316 (up to M4)*
- *Thermal spacers: G10 and Teflon*
- *Support brackets: AA 6061*
- *Insulation: MLI*

General construction

- *Pressurized volume is an all welded sealed system. Weld types included are:*
 - *Gas Tungsten Arc Welding (Orbital welding)*
 - *Laser welding*
 - *Inertia welding (Aluminum to stainless steel)*
- *No connectors are foreseen, but may be introduced later due to assembly constrains. (Candidate connector supplier: Dynatube)*
- *Thermal interface connection of copper heat sinks to stainless steel tubes by soft soldering with Sn96Ag filler.*
- *Glued interfaces using AV138m/HV998 glue (Thermal joints, non structural)*
- *Use of NASA provided bolts from #10. (Use of self provided metric bolts up to M4)*

TTCS Thermal Requirements

TTCB (Component box) thermal requirements:

- *Operating temperature:*
-50 °C / +25 °C
- *Survival temperature:*
-50 °C / +80 °C
- *Allocated power:*
70 Watt

Evaporator thermal requirements:

- *Operating temperature:*
-20 °C / +25 °C
- *Survival temperature:*
-40 °C / +80 °C

TTCE (Control electronics) thermal requirements:

- *Operating temperature:*
-20 °C / +55 °C
- *Survival temperature:*
-40 °C / +80 °C
- *Allocated power:*
3.5 Watt

Condenser thermal requirements:

- *Operating temperature:*
-50 °C / +25 °C
- *Survival temperature:*
-100 °C / +80 °C

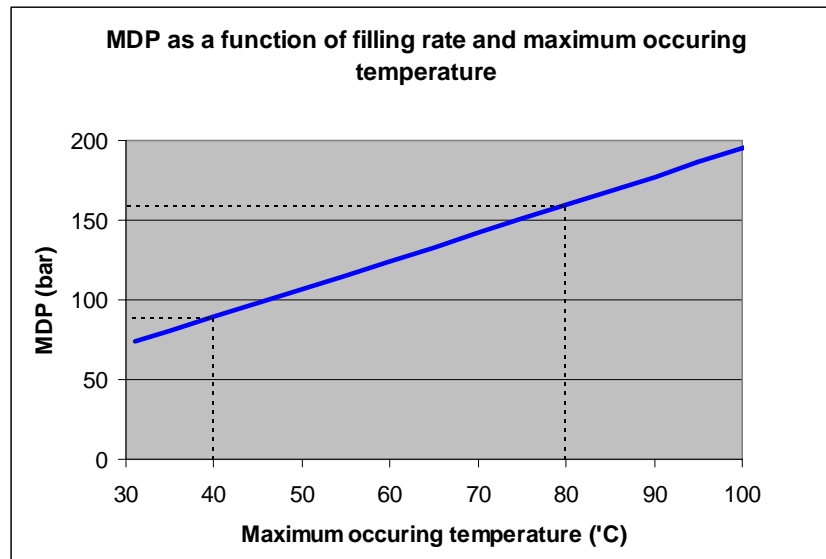
TTCS Structural Requirements

(Applicable documents)

- *Pressurized components designed and tested according to:*
MIL-STD-1522A,
(Standard General Requirements For Safe Design And Operation Of Pressurized Missile And Space Systems)
- *Pressurized welds are manufactured and tested according to:*
PRC-0010, Rev. A., class B.
(Process Specification for Automatic and Machine Arc Welding of Steel and Nickel Alloy Flight Hardware)
- *Non Pressurized hardware is designed according to:*
JSC-20545 Rev A.
(Simplified Design Options for STS-Payloads)

Other TTCS design criteria:

- **Maximum Design Pressure (MDP):** 160 bar (@ 80°C)
- **TTCS Volume per system:** 1.9 Liter
- **Accumulator Volume** 1.3 Liter
- **TTCS CO₂ filling per system:** 874 gram
- **Allowed system leak rate:** $1 \cdot 10^{-6}$ mbar*l/s
- **Mission duration:** 5 Years



TTCS verification (1/2)

Performance testing:

- *Under normal atmospheric conditions (Insulated):*
 - *Full scale development breadboard model*
 - *Flight hardware system testing using a cold plate (Radiator removed)*

Thermal Vacuum tests:

- *Thermal cycling*
 - *on all relevant subsystems and components for qualification*
- *Thermal balance and thermal vacuum performance tests*
 - *on subsystem level when necessary for system performance, e.g.:*
 - *Thermal Bars,*
 - *TTCS Box*
- *Complete system level test of the TTCS during AMS-02 overall thermal vacuum testing.*

TTCS verification (2/2)

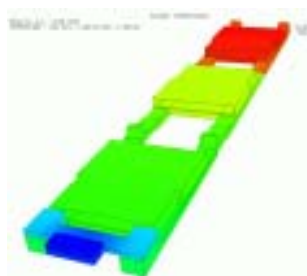
EMC/EMI:

- *Electromagnetic compatibility/interference testing on all relevant subsystems*

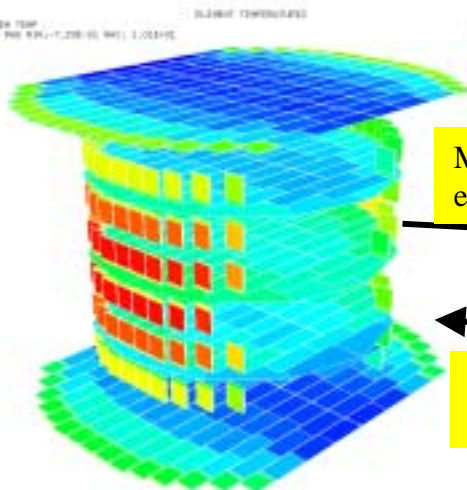
Structural testing:

- *Proof pressure on flight hardware (Components, TTCS assembly)*
- *Burst pressure tests using non-flight hardware (On components only)*
- *Leak testing:*
 - *Helium leak tests on flight components*
 - *Pressure decay test on the complete TTCS after proof pressure testing*
- *Vibration testing:*
 - *Thermal bars (Prototype hardware)*
 - *TTCB (Component box)*
 - *TTCE (Electronics crate)*

TTCS Thermal Modeling



Thermal model of detector with conductors represented as links (I-DEAS, NIKHEF)



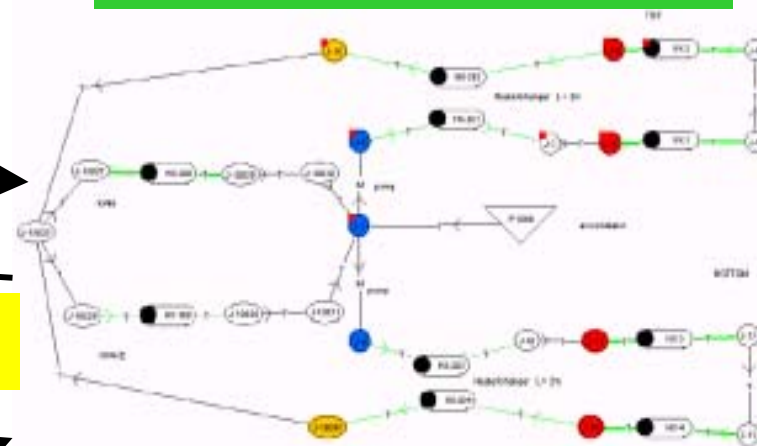
Model exchange

Cooling system set point

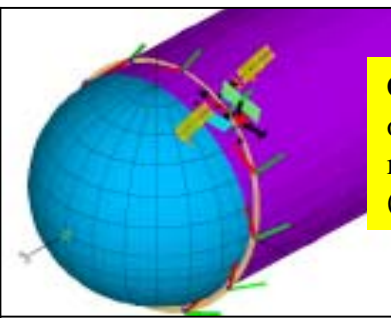
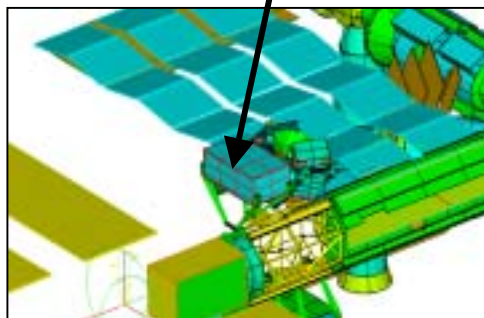
Model exchange

Orbital fluxes boundary conditions

Cooling system modeling with fluid properties (SINDA/Fluint, NLR/Noordoostpolder)



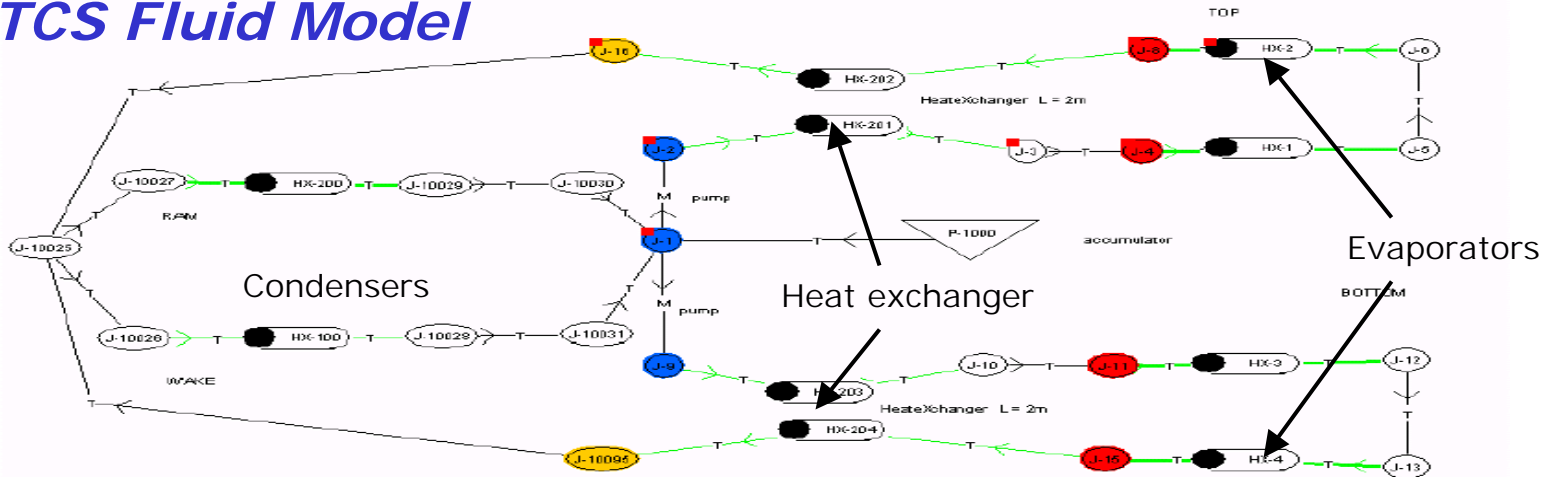
Cooling system set point and power dissipation



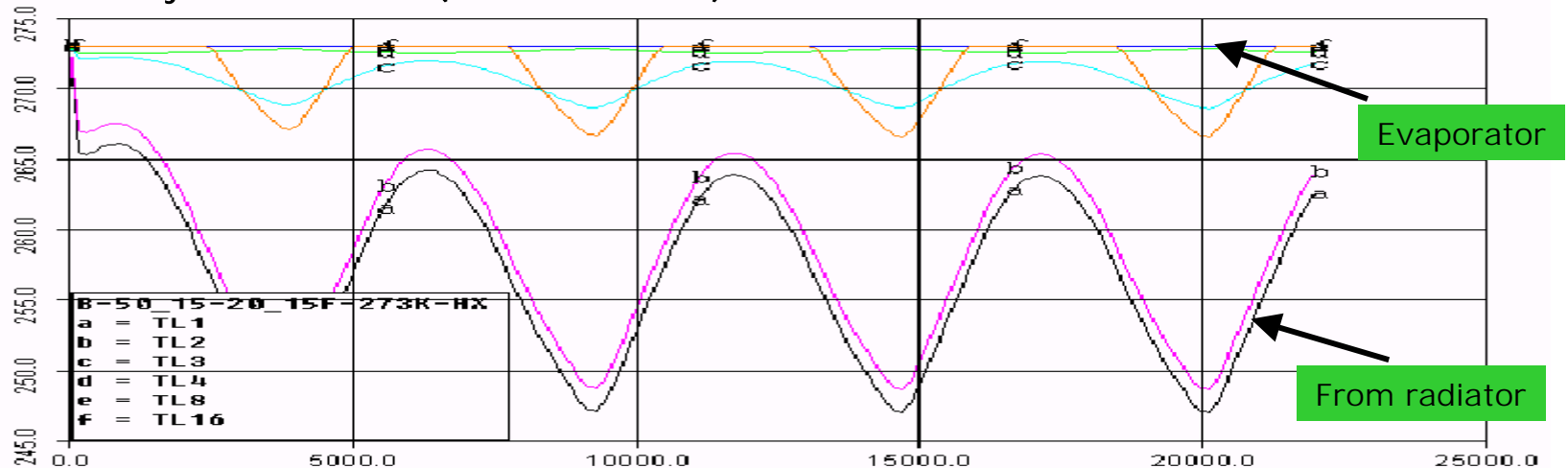
Complete AMS thermal model on International Space Station model to calculate orbital fluxes. (SINDA, CGS/Milan)

Tracker Thermal Control System

TTCS Fluid Model

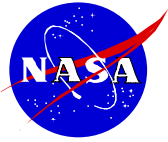


Typical TTCS dynamic behavior (From fluid model)





AMS-02 Thermal and Thermal Control System



AMS-02 Thermal Overview

- **AMS-02 delivered to ISS in shuttle payload bay**
- **Permanently mounted on S3, inboard, zenith site**
- **Payload has 2000 watts of heat dissipation**
- **Must meet all ISS and STS safety requirements**
- **Must comply with SSP 57003 (Attached Payload Interface Requirements Document)**



ISS Thermal Requirements

- **SSP 57003, Attached Payload Interface Requirements Document, is the primary controlling document for all AMS-02 thermal requirements relating to ISS.**
- **Applicable sections include:**
 - 3.1.1.2.5 THERMAL EFFECTS**
 - 3.4.1.1.1 TEMPERATURE REQUIREMENT**
 - 3.4.1.1.5 THERMAL RADIATION MODELS**
 - 3.4.1.1.6 THERMAL EXCHANGE BETWEEN PAYLOADS**
 - 3.5.1.2 THERMAL ENVIRONMENT**
 - 3.7.6.1 EBCS AVIONICS PACKAGE ENVELOPE AND MOUNTING**
 - 3.7.6.2 EBCS AVIONICS PACKAGE POWER**
 - 3.7.6.3 EBCS THERMAL REQUIREMENTS**



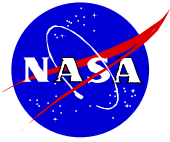
ISS Thermal Requirements (SSP 57003)

3.1.1.2.5 THERMAL EFFECTS

Attached Payload structure shall meet interface requirements when subjected to structural interface temperatures ranging from –120 degrees F to +200 degrees F when combined with static and dynamics loads.

3.4.1.1.1 TEMPERATURE REQUIREMENT

The Attached Payload to the S3 PAS and P3 UCCAS interfaces shall meet all requirements specified when the structural interface temperature is within –120 Deg. F and +200 Deg. F.



ISS Thermal Requirements (SSP 57003)

3.4.1.1.5 THERMAL RADIATION MODELS

- A. Simplified thermal models of the Attached Payloads shall be provided to the ISS Program by the payload developer.**
- B. The Attached Payload simplified thermal models shall identify all surfaces over 10% specular and specular values for those surfaces shall be provided.**



ISS Thermal Requirements (SSP 57003)

3.4.1.1.6 THERMAL EXCHANGE BETWEEN PAYLOADS

A. Attached Payload active radiation surfaces (surfaces designed to reject heat generated by the payload) shall be oriented so that they have a cumulative view factor no greater than 0.1 to any surface of the generic attached payload operational envelope as defined in Figure 3.1.3.1.1.1-1 placed on any other S3 or P3 attach site. The view factor as used here is defined as the fraction of diffuse radiation leaving surface 1 that will fall on surface 2, such that:

$$A1F1-2 = A2F2-1$$

Where A1 = area of surface 1

A2 = area of surface 2

F1-2 = view factor from surface 1 to surface 2

F2-1 = view factor from surface 2 to surface 1

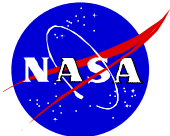
B. Attached Payload surfaces with a view to other Attached Payloads shall have a specularility of 10% or less.



ISS Thermal Requirements (SSP 57003)

3.5.1.2 THERMAL ENVIRONMENT

The Attached Payload will be exposed to thermal solar constants, albedo, and earth Outgoing Long-wave Radiation (OLR) environments as defined in Table 3.5.1.2–1; a space sink temperature of 3 K; the induced thruster plume environment and induced thermal environments from vehicle(s) docking and docked with the ISS; and thermal interactions with other on-orbit segments. Induced thermal effects on Attached Payloads due to beta angle extremes, orbital altitude, and attitude variation about the ISS vehicle axes are provided in Table 3.5.1.2–2. These environments are to be used for design and analysis purposes.



ISS Thermal Requirements (SSP 57003)

TABLE 3.5.1.2–1 HOT AND COLD NATURAL THERMAL ENVIRONMENTS

Case	Solar Constant (W/m²)	Earth Albedo	Earth Outgoing Long Wave Radiation (W/m²)
Cold	1321	0.2	206
Hot	1423	0.4	286



ISS Thermal Requirements (SSP 57003)

TABLE 3.5.1.2-2 INDUCED THERMAL ENVIRONMENTS

Induced Environment	Assumed Parameters
Beta Angle	$\pm 75^\circ$
Altitude	150 nmi. to 270 nmi.
Attitude Envelope Without Orbiter ⁽¹⁾	Any combination of $\pm 15^\circ$ Roll (about X axis) ⁽²⁾ $\pm 15^\circ$ Yaw (about Z axis) ⁽²⁾ $+15$ to -20° Pitch (about Y axis) ⁽²⁾
Attitude Envelope With Orbiter Docked to ISS ⁽¹⁾	Any combination of $\pm 15^\circ$ Roll $\pm 15^\circ$ Yaw 0 to -25° Pitch

Note(s):

- 1) The attitude variations include variations in the Torque Equilibrium Attitude (TEA) as well as variations in the ISS attitude from the TEA attitude, both with Orbiter docked, and without Orbiter.
- 2) XYZ axes refer to ISS coordinate system orientation.



ISS Thermal Requirements

3.7.6.1 EBCS AVIONICS PACKAGE ENVELOPE AND MOUNTING

C. The payload shall maintain the location of the EBCS Avionic Package mounting surface as specified in B above, after exposure to vibration and impact loads and during exposure to the on-orbit thermal environment conditions specified herein.



ISS Thermal Requirements (SSP 57003)

3.7.6.2 EBCS AVIONICS PACKAGE POWER

- A. The payload shall route the PVGF cable to the EBCS Avionics Package and provide connections as indicated in SSP 57004, Figure 3.7.2–1. The Avionics Package uses power from the PVGF and also routes payload power from the PVGF to the payload, up to 1800 Watts if necessary.**

The Avionics Package will receive 30 Watts, compatible with the MSS power quality requirements specified in SSP 42004, paragraph 3.2.1.5.1, during payload berth and unberth operations.

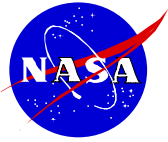
- B. The payload shall provide 2 heater busses, each capable of delivering 25 W (TBR #8), to the Avionics Package for keep-alive heater power.**



ISS Thermal Requirements (SSP 57003)

3.7.6.3 EBCS THERMAL REQUIREMENTS

- A. Thermal Conductivity
(TBD #16)**
- B. EBCS Non-Operational On-Orbit
(TBD #16)**
- C. EBCS Operational On-Orbit
(TBD #16)**



STS Thermal Requirements

- **Provide AMS-02 thermal model to STS for payload compatibility analysis. Must include temperature limits for all applicable nodes and optical properties for all external surfaces.**
- **Evaluation of Failed Open Vent Door case**

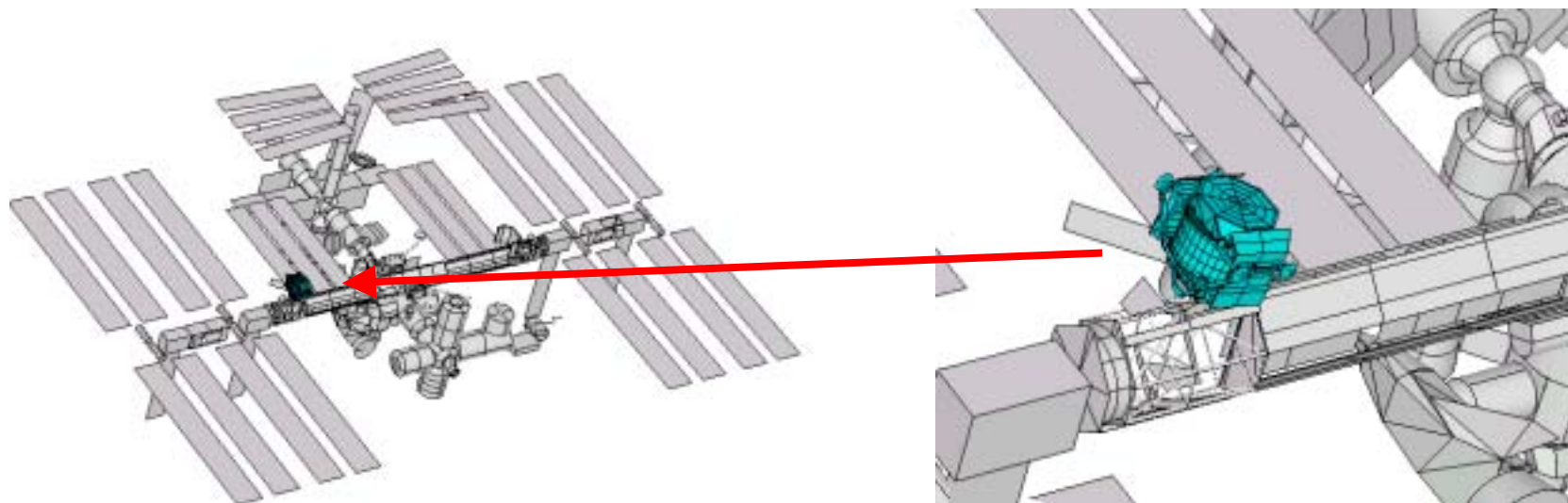


Thermal Safety Requirements

- **EVA Touch Temperature**
 - **Incidental contact with surfaces that exceed -180°F to $+235^{\circ}\text{F}$**
 - **Unlimited contact with surfaces that exceed -45°F to $+145^{\circ}\text{F}$**
- **Failed heaters**
 - **Temperature predictions for thermostatically controlled surfaces assuming all heater fail “on”**
- **Auto-ignition**
 - **Verify that no surfaces can exceed $+352^{\circ}\text{F}$ while in orbiter payload bay**

ASSUMED ISS CONFIGURATIONS

- ISS Assembly Complete (AC)
- AMS-02 attached to S3, inboard, zenith Payload site
- With and without orbiter docked to ISS
- With and without adjacent payload (outboard site)





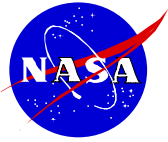
MISSION PHASES

- **Ground operations**
- **Transport**
- **Pre-launch**
- **Launch**
- **STS On-orbit**
- **STS Docked to ISS**
- **Transfer between STS and ISS**
- **Nominal ISS operation**
- **Landing**



OPERATING SCENARIOS

- **STS payload bay operations**
- **Transfer from STS to ISS (power via PVGF)**
- **Start-up Scenario (includes pre-heating, detector power up, Magnet charging, etc.)**
- **Nominal ISS operation (full power)**
- **Magnet discharging**
- **Keep Alive (survival power)**



AMS-02 THERMAL DESIGN GOALS

- **Meet all ISS, STS, and safety requirements**
- **Maintain all experiment components and sub-detectors within specified operating and survival limits (document in AMS-02 Thermal ICD)**
- **Maximize Super Fluid Helium (SFHe) endurance**
- **Optimize sub-detector temperatures to maximize science**



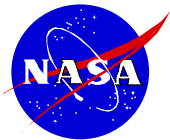
THERMAL RESPONSIBILITIES

- **Lockheed Martin Space Operations (LMSO), through the NASA Mission Planning and Integration Office (MPIO), is responsible for interfaces to NASA (ISS and STS), verification of NASA requirements, and all safety related issues. LMSO is also providing general thermal consultation to experiment team.**
- **Carlo Gavazzi Space (CGS), through contract with the AMS collaboration, is responsible for integrated payload thermal design, analysis, and testing. They are also responsible for system level thermal hardware delivery and integration.**
- **AMS02 Sub-detector groups are responsible for their own thermal design, modeling and hardware. Sub-detector analysis is performed in conjunction with integrated thermal analysis performed by CGS.**

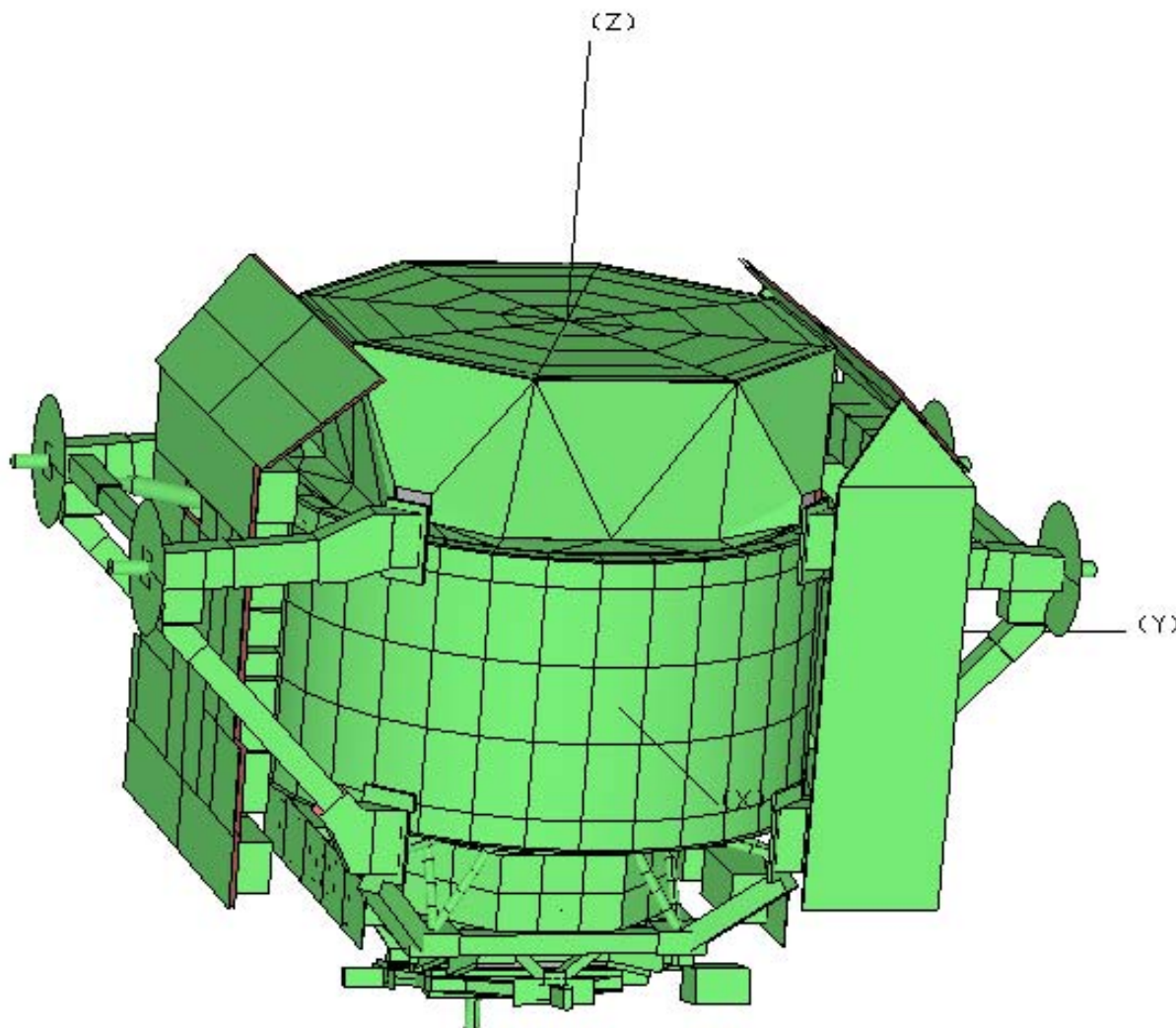


THERMAL RESPONSIBILITIES (continued)

- Sub-detector thermal responsibilities include:
 - USS02 (including ISS & STS integration hardware) – LMSO
 - Vacuum Case –LMSO
 - Cryo-magnet –SCL
 - Cryo-coolers – MIT/GSFC
 - Cryo-cooler cooling system - CGS/OHB/GSFC
 - Radiators – CGS/OHB
 - Electronic Crates – MIT/CGS/NSPO/CSIST
 - TRD – OHB
 - TOF – CGS
 - Tracker – NLR/Nikhef
 - ACC – RWTH
 - RICH – CGS
 - ECAL – CGS
 - CAB – CRISA
 - UPS – CSIST
 - CCEB – ETH
 - TRD Gas System – MIT/CGS/LM

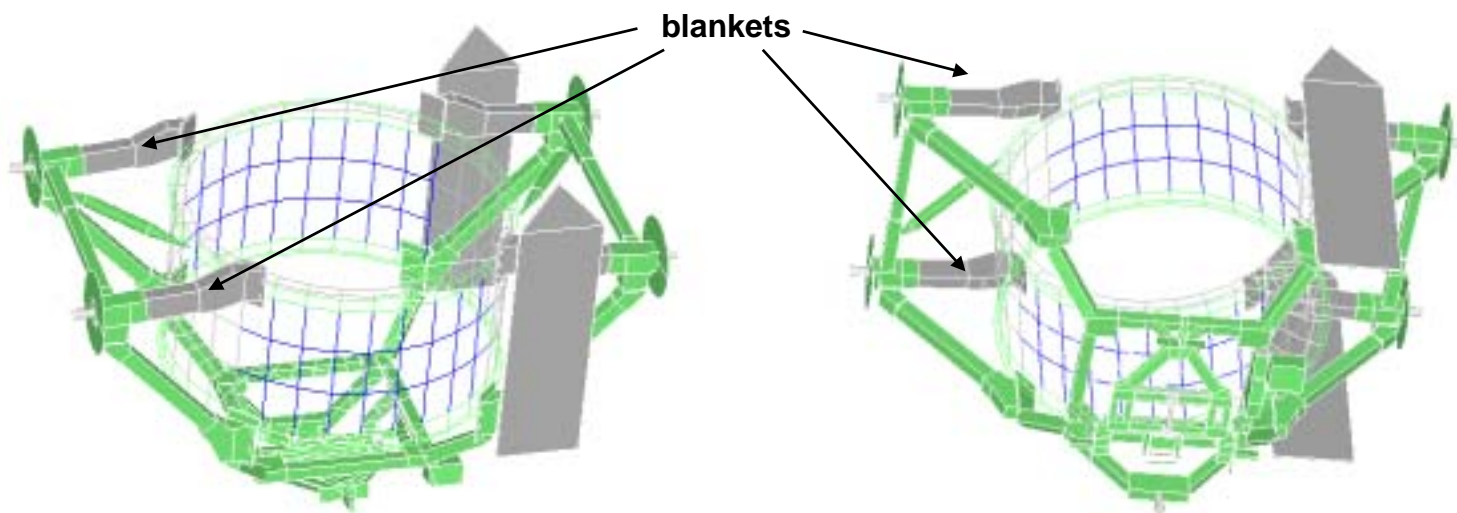


AMS-02 DESCRIPTION



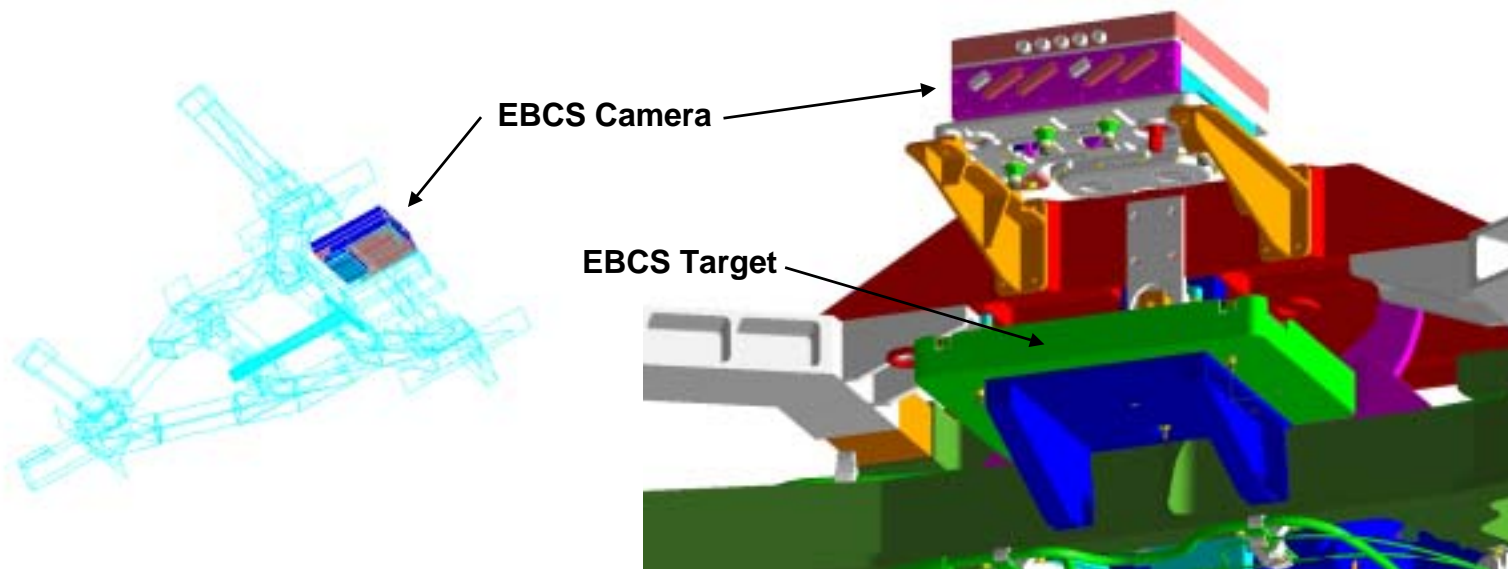
USS-02

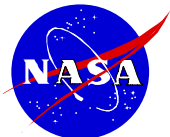
- No heat dissipation
- Primarily anodized aluminum
- Provides structural interface to ISS, STS and AMS-02 sub-detectors
- Thermal blankets on joints and trunnion bridges are being considered to help reduce gradients at TRD I/F's.



INTEGRATION HARDWARE

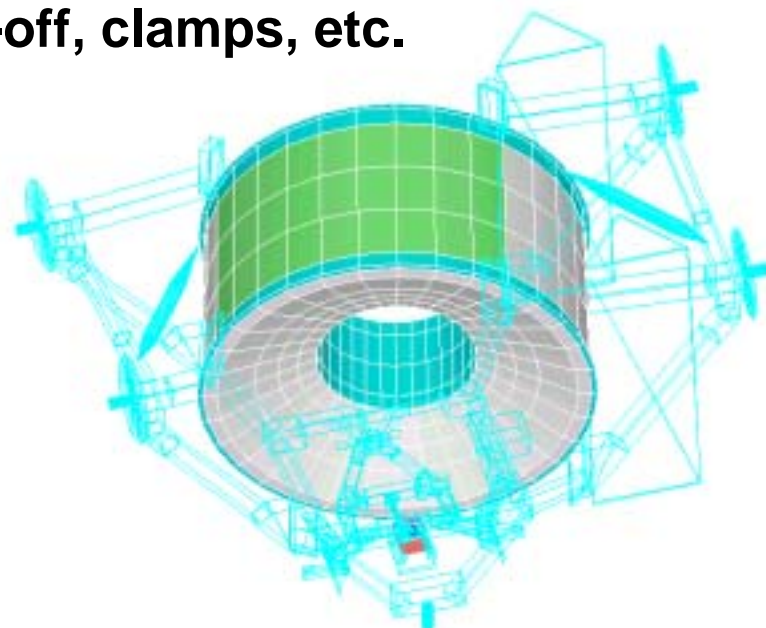
- **Unpowered Hardware: Power & Video Grapple Fixture (PVGF), Flight Releasable Grapple Fixture (FRGF), Umbilical Mechanism Assembly (UMA), Payload Disconnect Assembly (PDA), and EVA Connector Panel**
- **External Berthing Camera System (EBCS) will be used to berth (and unberth) AMS-02. Camera will be power “on”, whenever payload is grappled by the PVGF. Survival heaters will be activated constantly while AMS is powered through the UMA.**





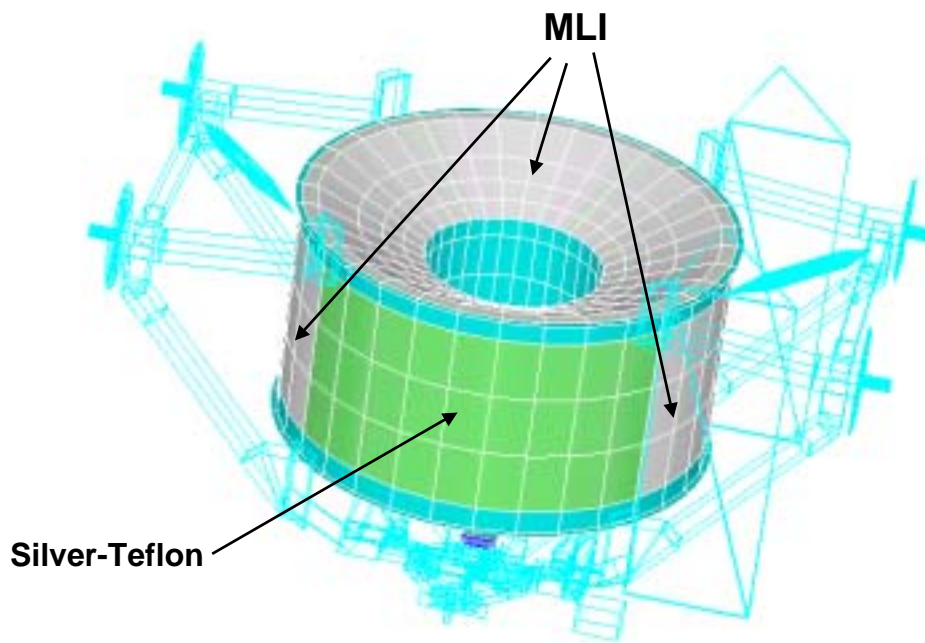
VACUUM CASE

- VC needs to be “cold as possible” to maximize SFHe endurance
- Any hardware mounted to VC with significant heat dissipation will be thermally isolated. Hardware mounted to VC include:
 - Cryo-coolers
 - Anti-Coincidence Counter (ACC) Photo Multipliers (PM's)
 - Tracker Thermal Control System (TTCS)
 - Tracker Cables
 - Miscellaneous cables, stand-off, clamps, etc.



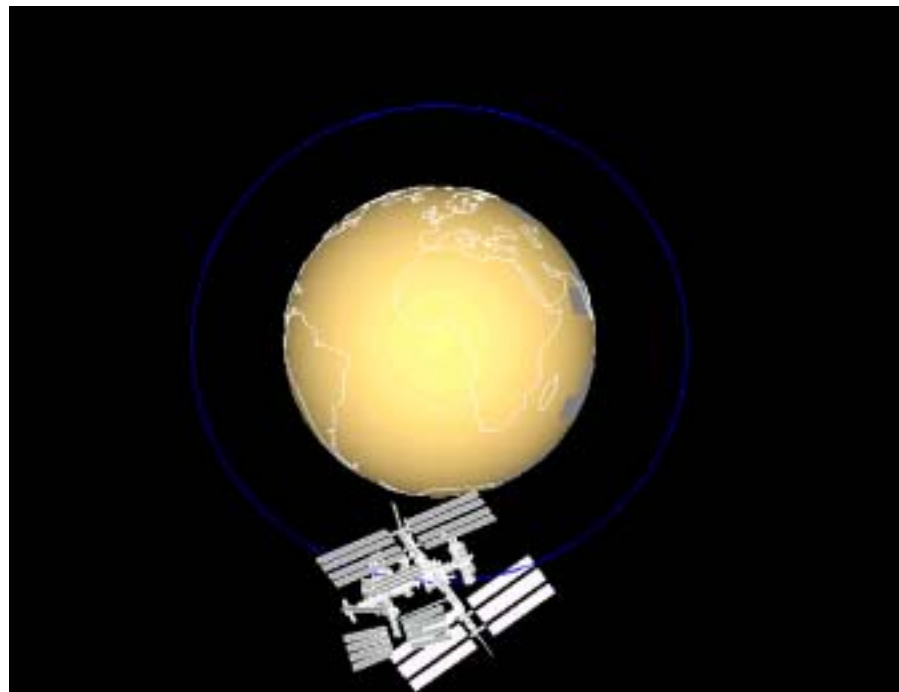
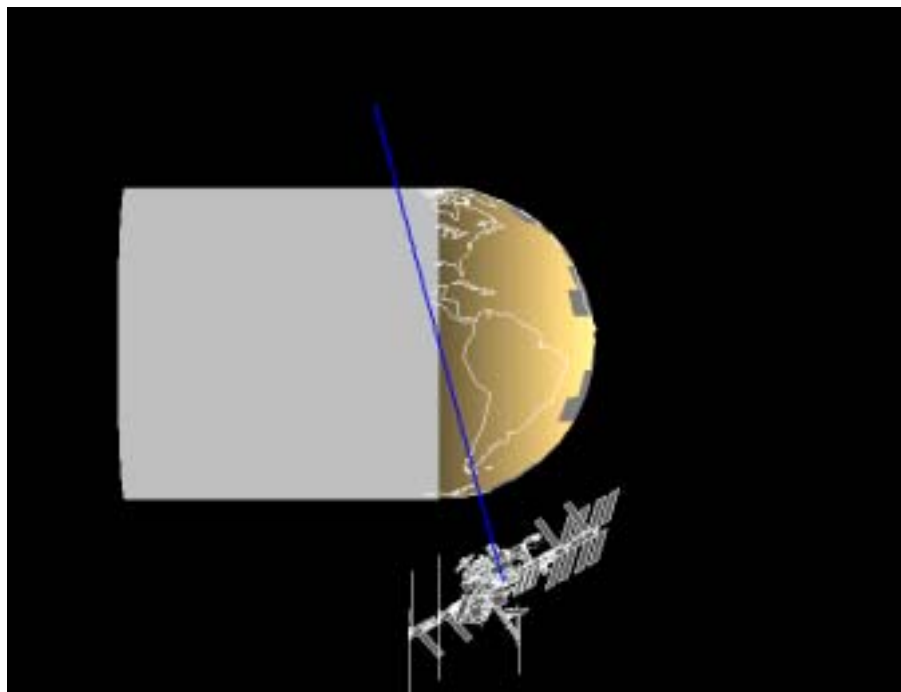
VACUUM CASE (continued)

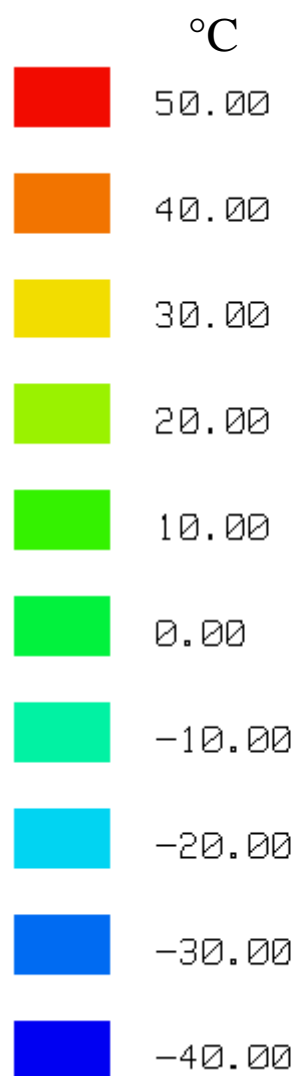
- Structural interfaces to USS-02, Tracker and ACC will also be thermally isolated.
- The VC will be covered with MLI blankets on +/- Y quadrants and silver-Teflon on +/-X quadrants. MLI blankets will also cover upper and lower conical flanges.



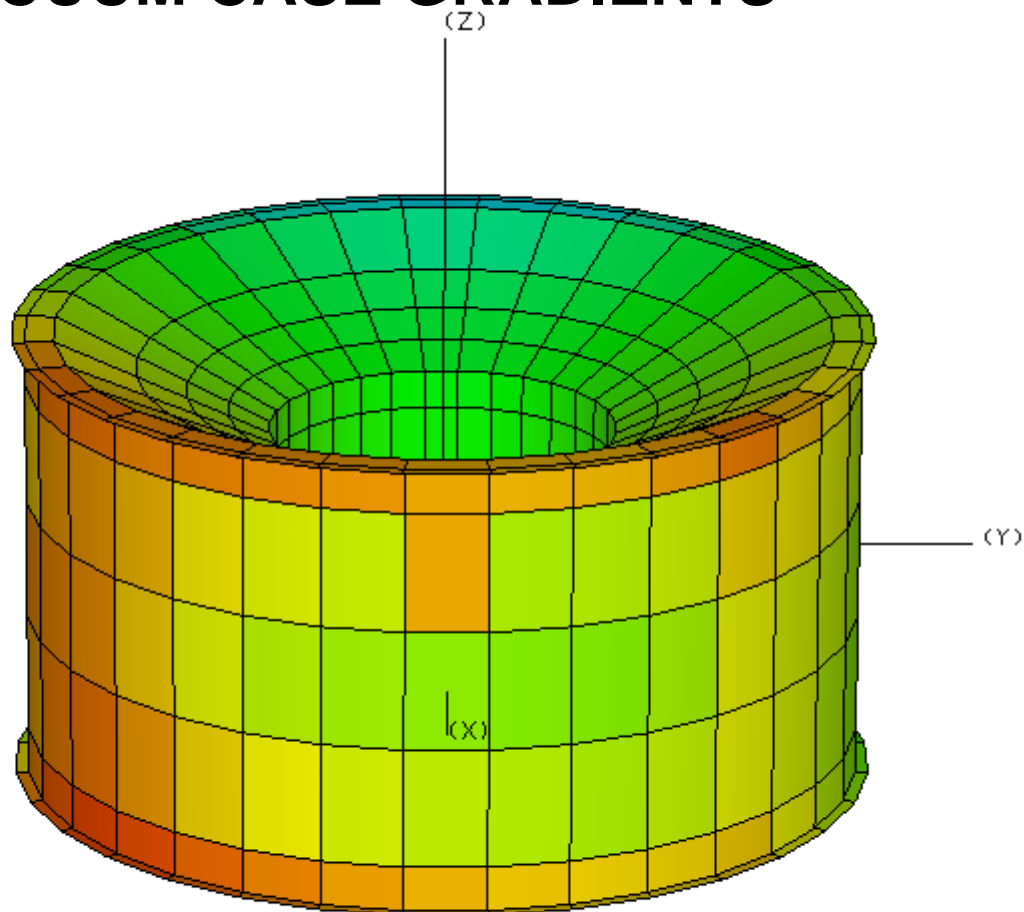
VACUUM CASE GRADIENTS

- Vacuum case temperature gradients have been considered in structural deflection analyses.
- Worst case gradients occur at $\beta = +75^\circ$, $YPR = -15^\circ, -20^\circ, -15^\circ$

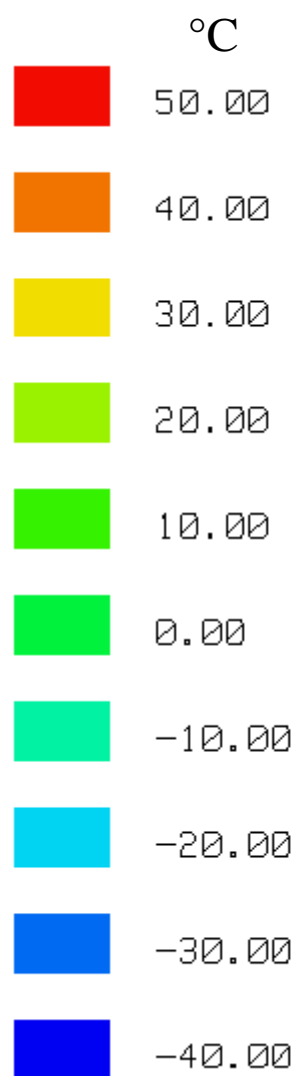




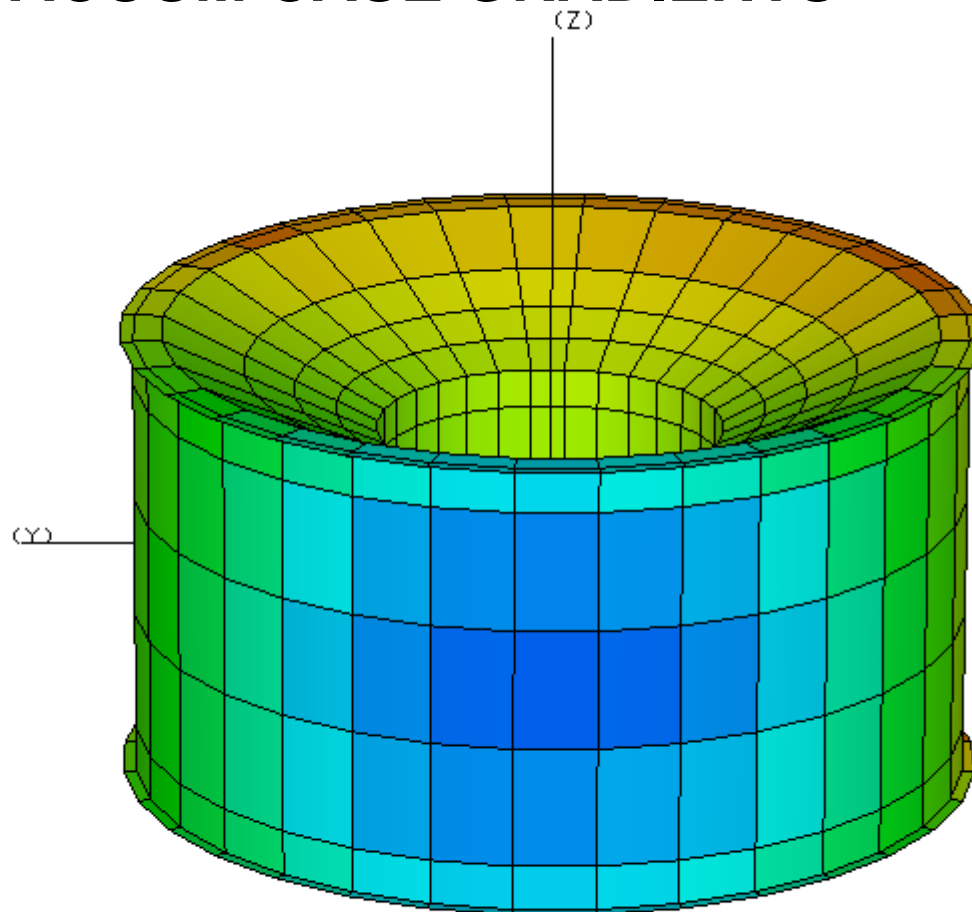
VACUUM CASE GRADIENTS



**Vacuum Case Maximum Delta T
B=+75, YPR=-15,-20,-15**



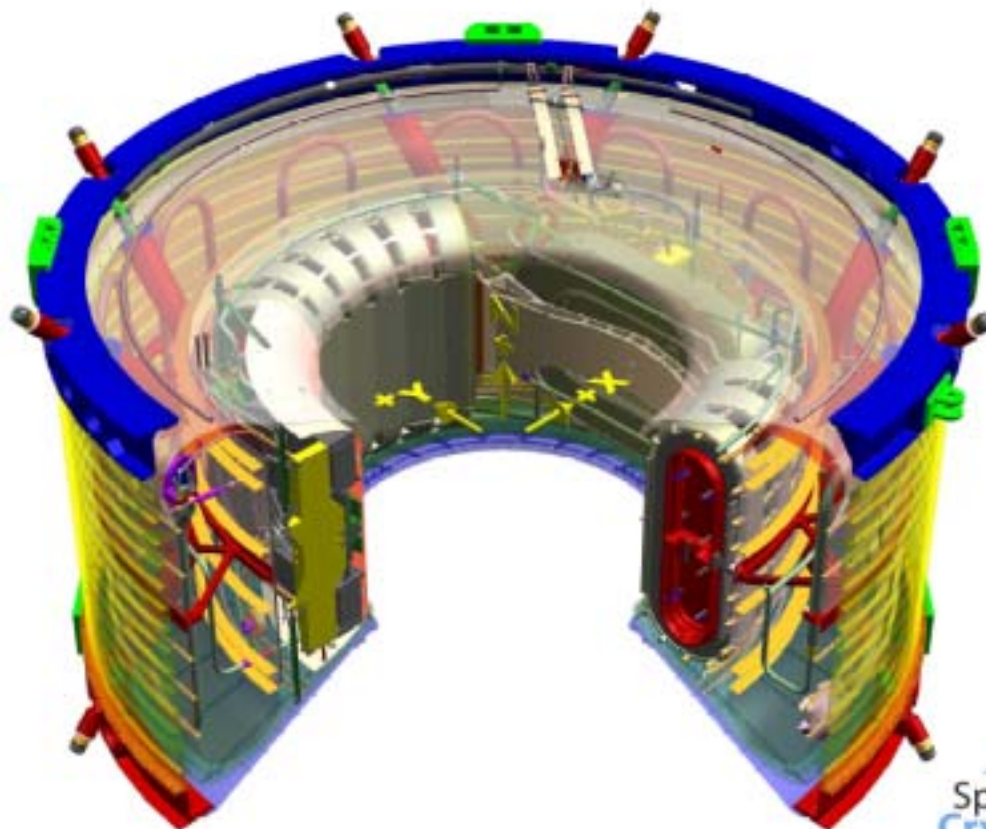
VACUUM CASE GRADIENTS



Vacuum Case Maximum Delta T
B=+75, YPR=-15,-20,-15

MAGNET

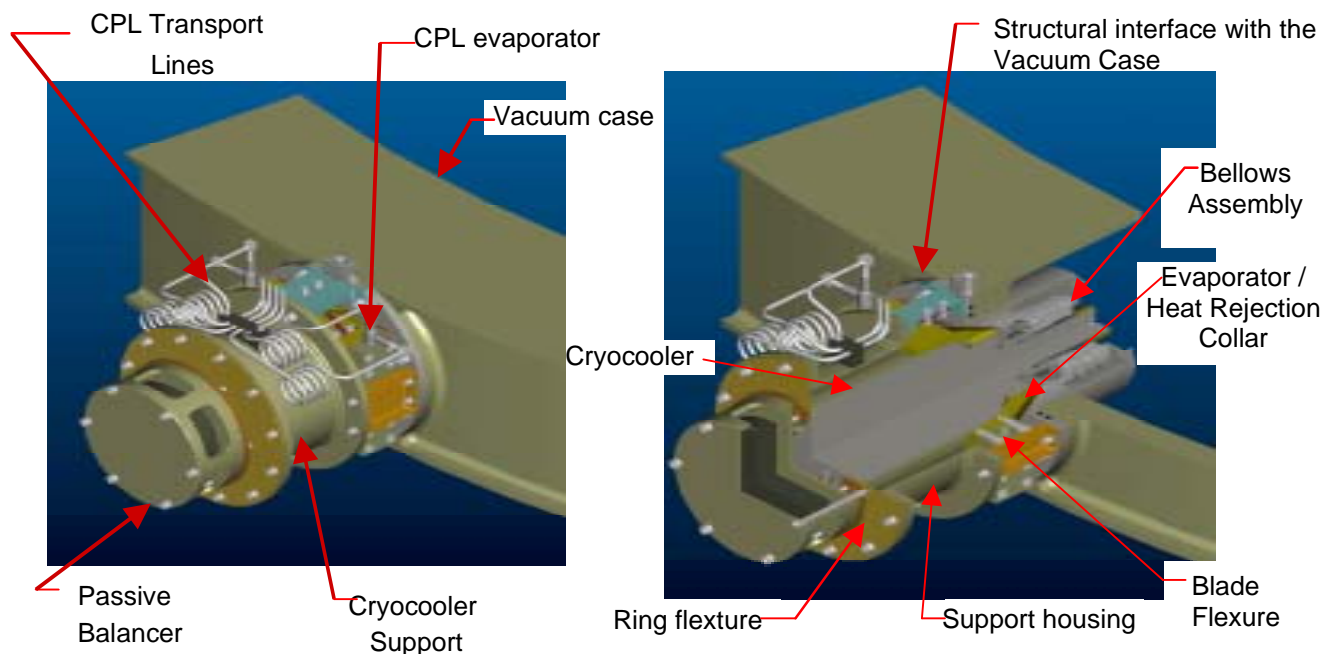
- By design magnet Cold Mass has minimal effect on VC temperature and is not included in thermal model. VC temperature, however, does play a significant role in heat leak into cold mass and therefore needs to be as cold as possible.



Space
Cryomagnetics

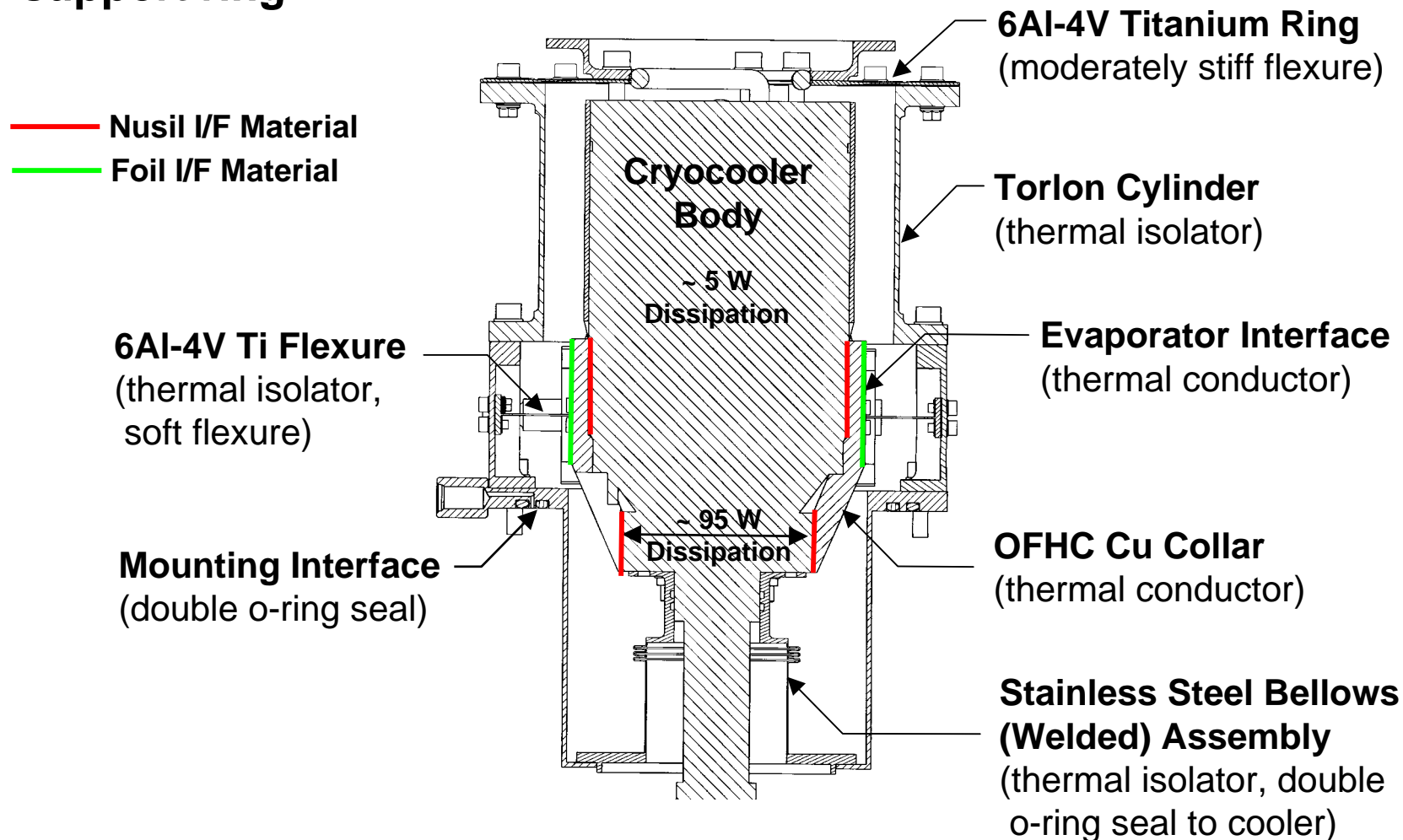
Cryo-coolers

- Cryo-coolers are used to cool the outer Vapor cooled shield to ~80K
- Cryo-coolers need to dissipate a significant amount of heat (100W x 4 units = 400W or 150W x 3 units = 450W), while maintaining heat rejection collar temperatures between -10°C and $+10^{\circ}\text{C}$ (design goal for optimum performance).



Cryo-cooler Mounting

- Cryo-cooler brackets provided isolation between cooler and VC support ring.



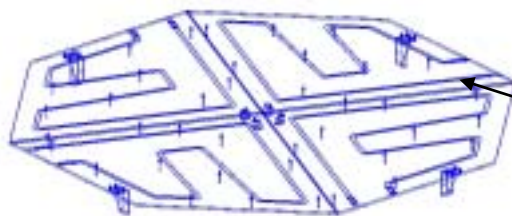
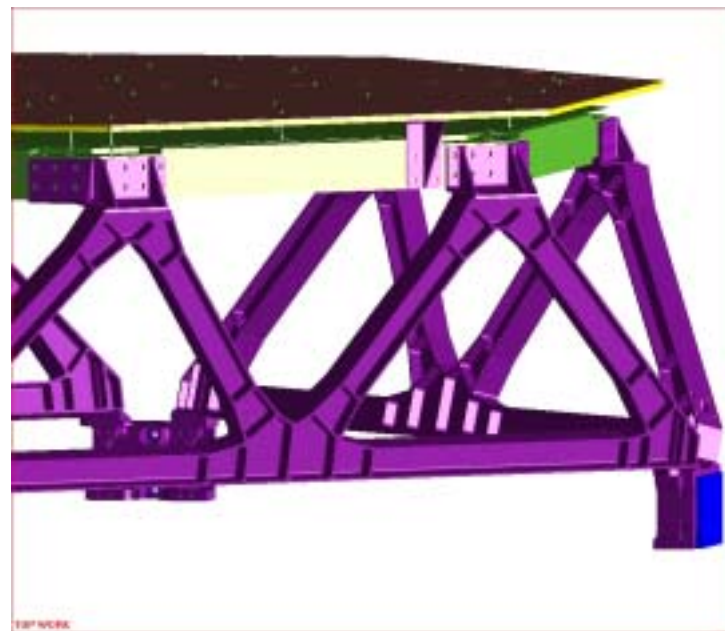
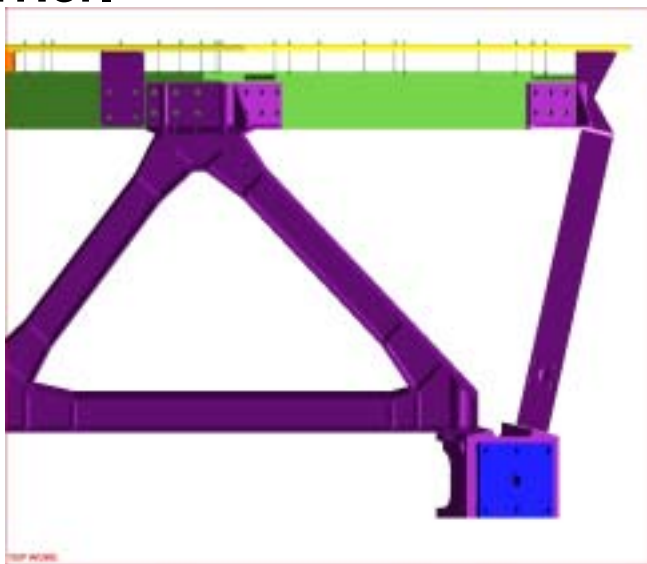


Cryo-Cooler Cooling - Loop Heat Pipe

- **Loop Heat Pipes (LHP) collect heat at each cryo-cooler and dissipate it by a direct flow zenith-mounted radiator.**
- **LHP built by TAIS/Moscow will be similar to one successfully demonstrated on orbit as part of COM2PLEX (STS-107).**
- **Ammonia working fluid with a Nickel wick.**
- **Stainless steel tubing (3mm) transitions to aluminum tubing in the radiator via a bi-metallic solder joint.**

Cryo-cooler Cooling – Zenith Radiator

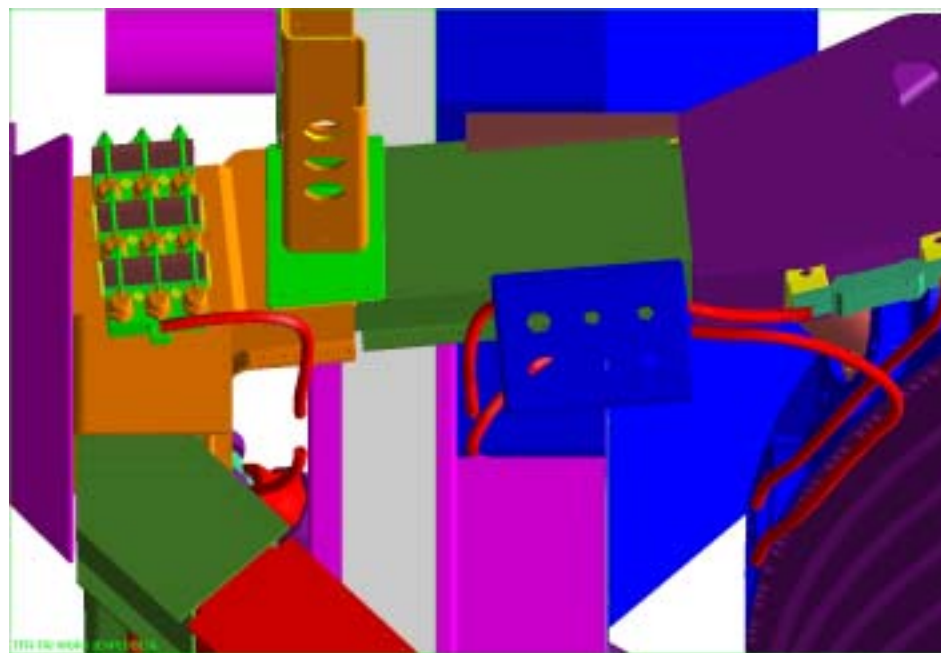
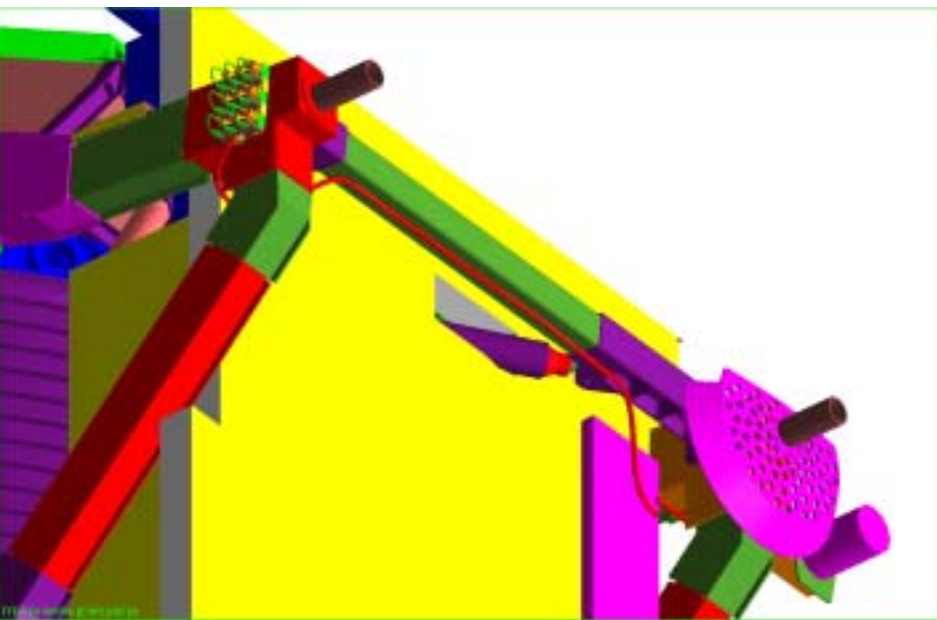
- Zenith radiator mounted on Upper TRD honeycomb plate.
- Thermal isolation provided by small support pins and a radiation barrier.

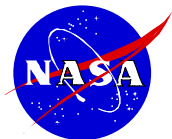


Tube Lay-Out
(3 mm OD)

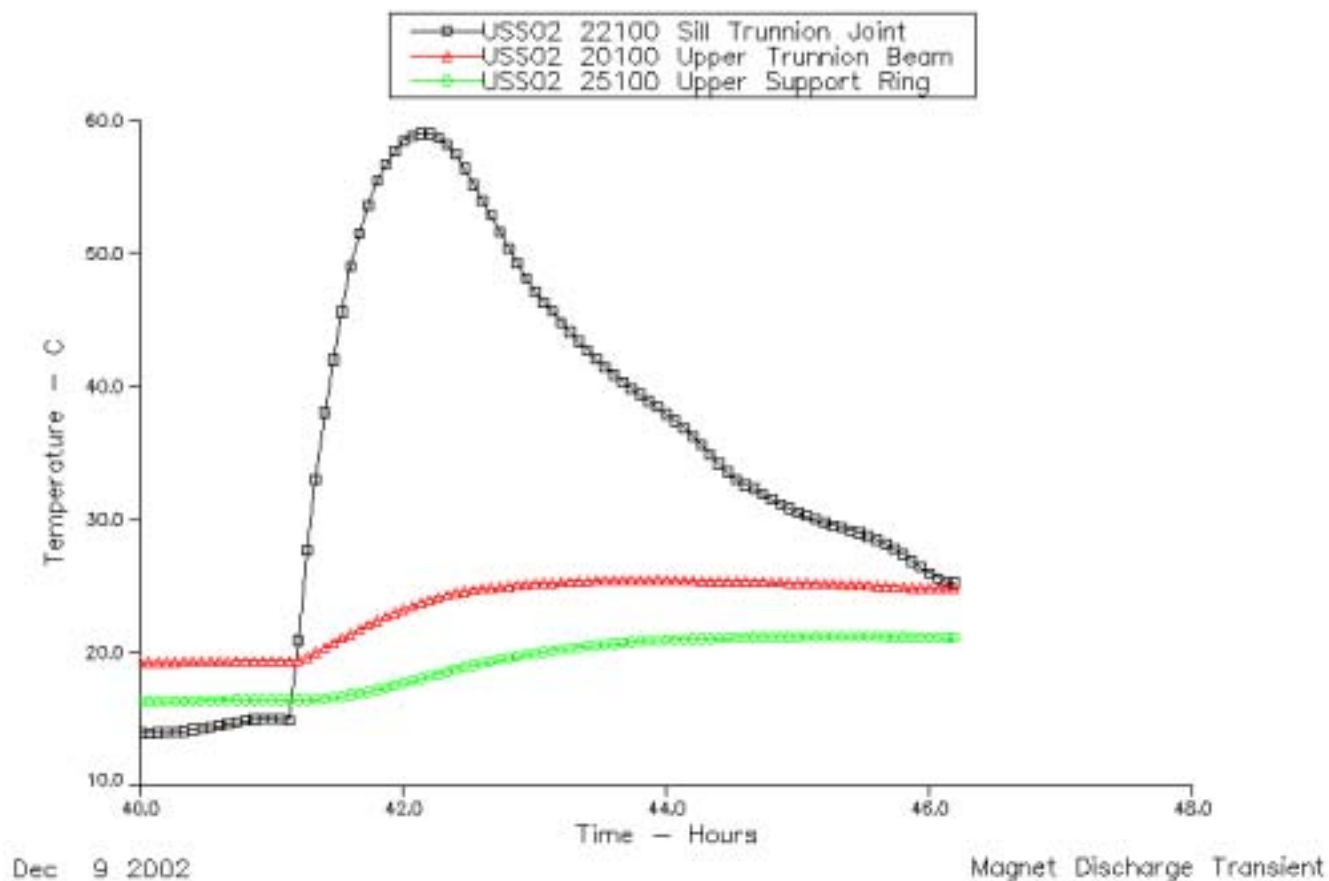
Cryo-Magnet Dump Diodes

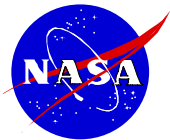
- Need to dissipate a significant amount of heat (5MJ over 2hr) when magnet is discharged. Sunk to USS-02 sill joints.





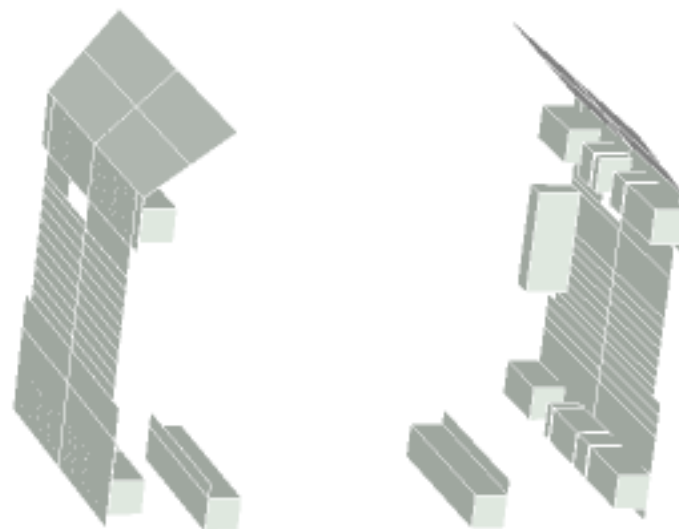
SILL JOINT TEMPERATURES (MAGNET DISCHARGE)



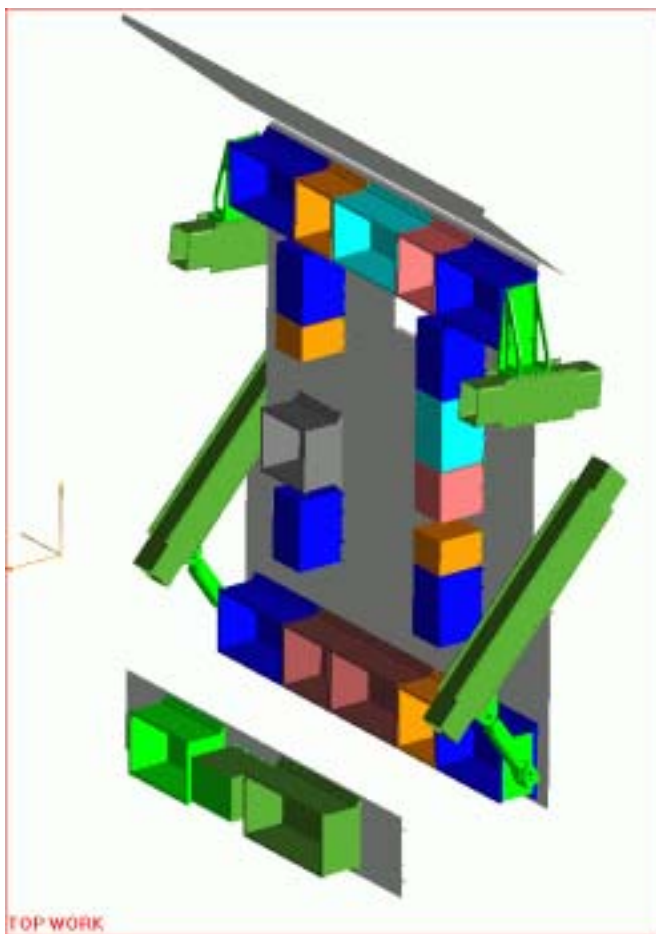


ELECTRONIC CRATES

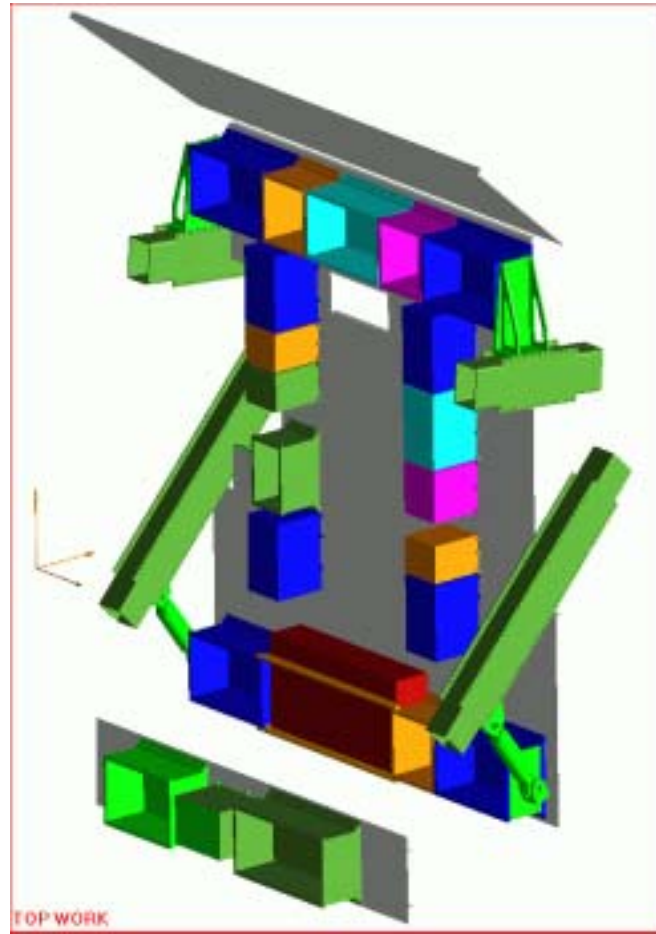
- Majority of all heat dissipation (~1500 W)
- With some exceptions, typical thermal limits are:
 - 20°C to +50°C (operating)
 - 40°C to +80°C (non-operating).
- MLI blankets will cover +/-X crate sides and some other surfaces with view to VC.



ELECTRONIC CRATES



RAM

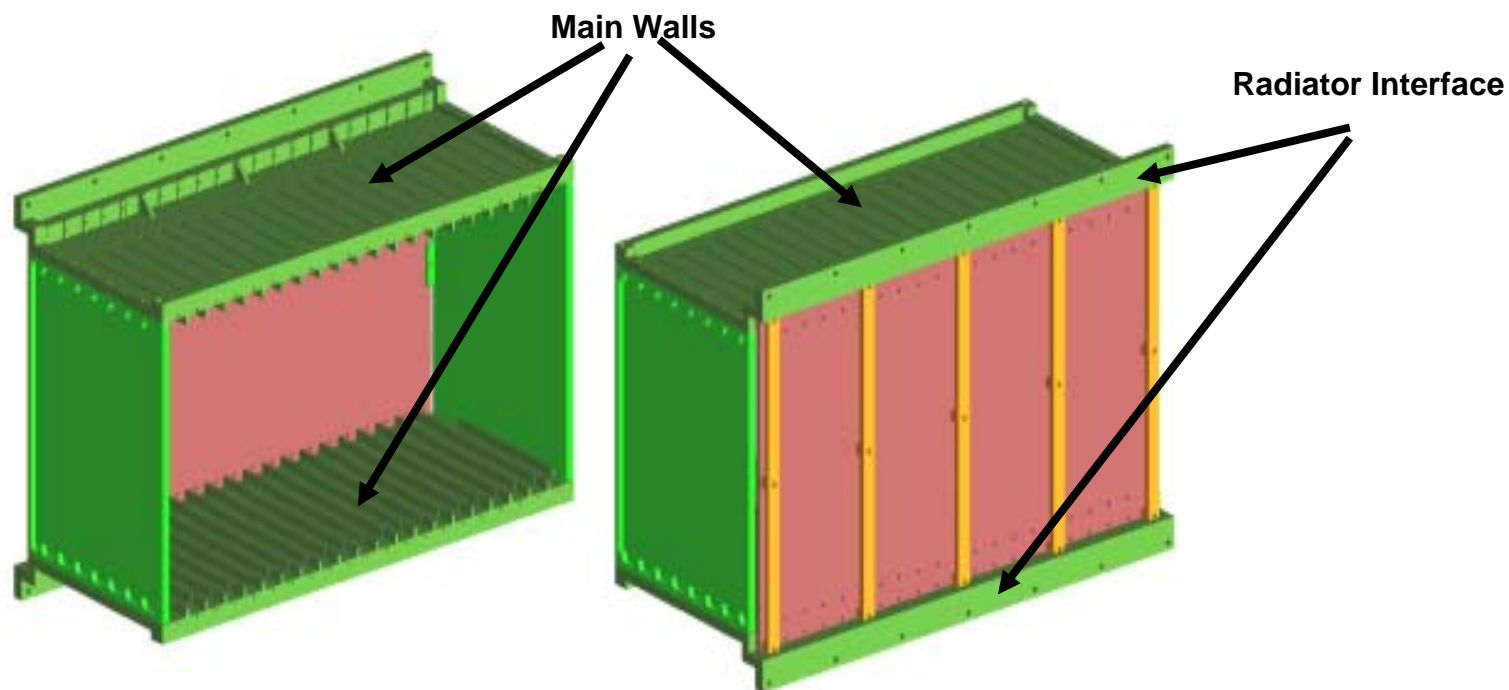


WAKE

□

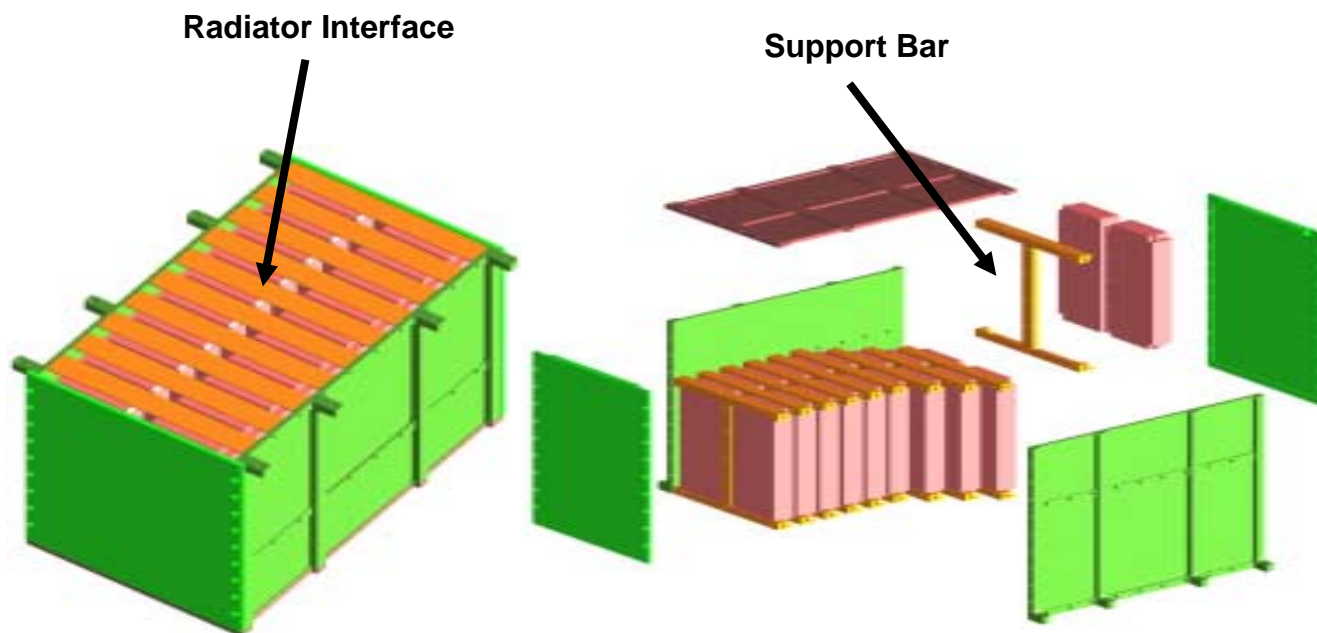
ELECTRONIC CRATES

- Crates are designed to dissipate heat from main walls directly attached to radiators.



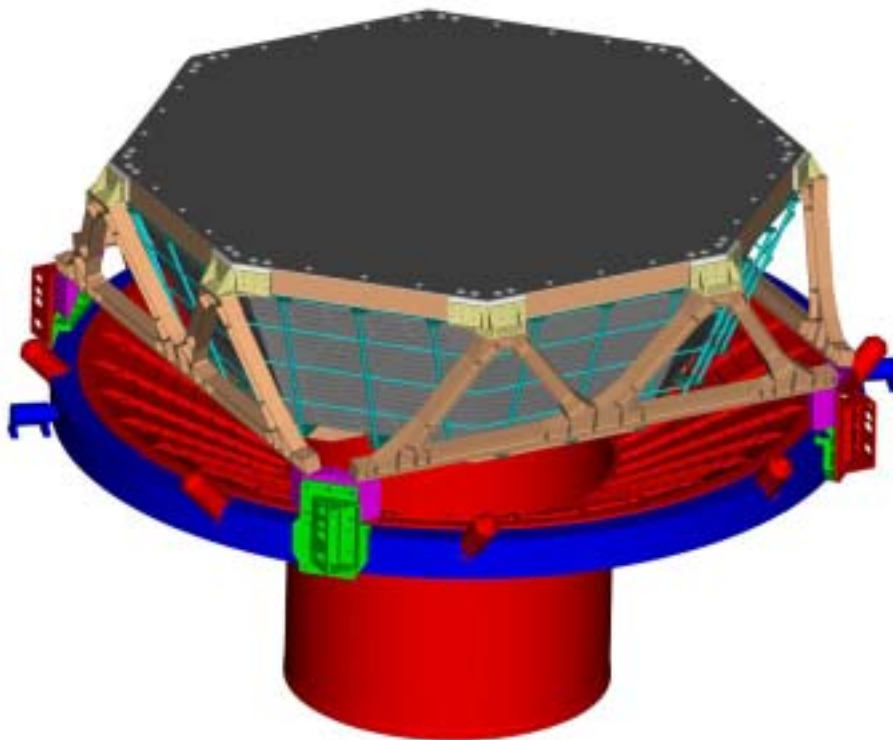
XPD's (POWER DISTRIBUTION UNITS)

- XPD's dissipate heat to radiators via “double T” shaped support bars.



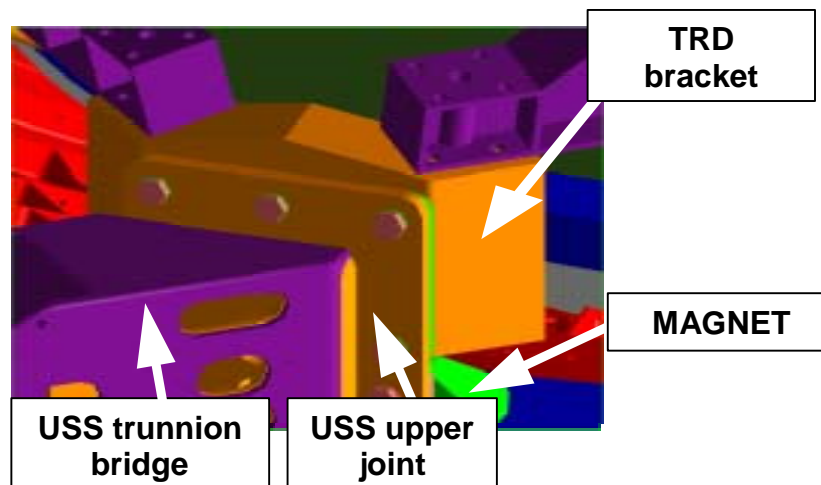
Transition Radiation Detector (TRD)

- Minimal heat dissipation (20W on periphery)
- Strict thermal requirements:
 - 5°C to +25°C operating, -20°C to +40°C non-operating
 - +/-1°C over an orbit
 - +/-1°C top to bottom
 - +/- 1°C on periphery



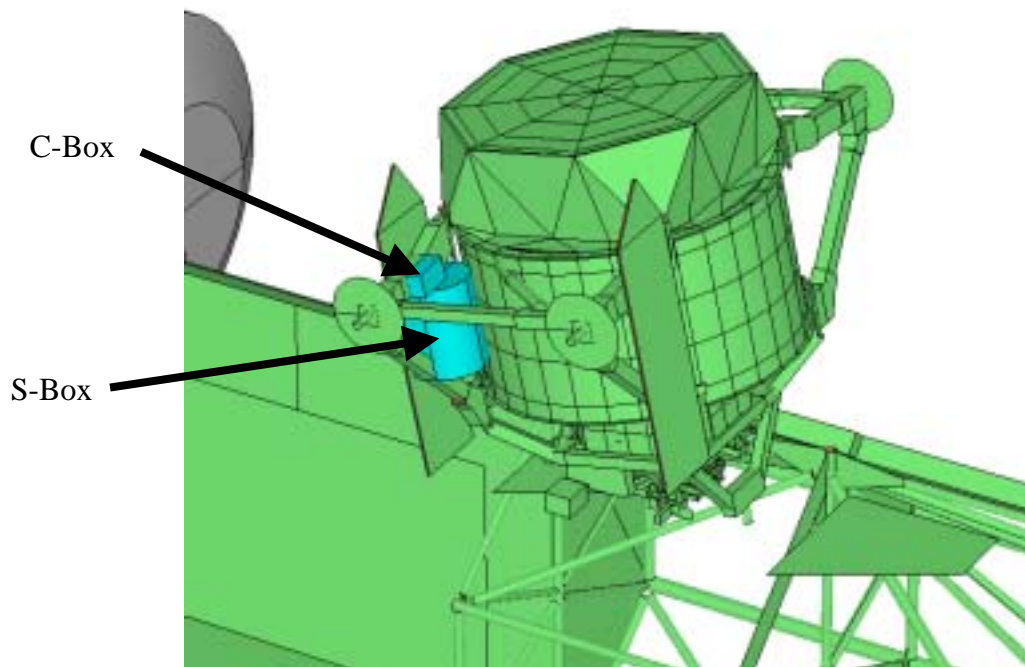
TRD

- Thermal control is passive. Heat rejected via radiation of TRD electronics on periphery and some conduction to USS-02.
- TRD (along with upper Time of Flight) enclosed in MLI.
- I/F to USS-02 is thermally isolated to reduce thermal gradients.



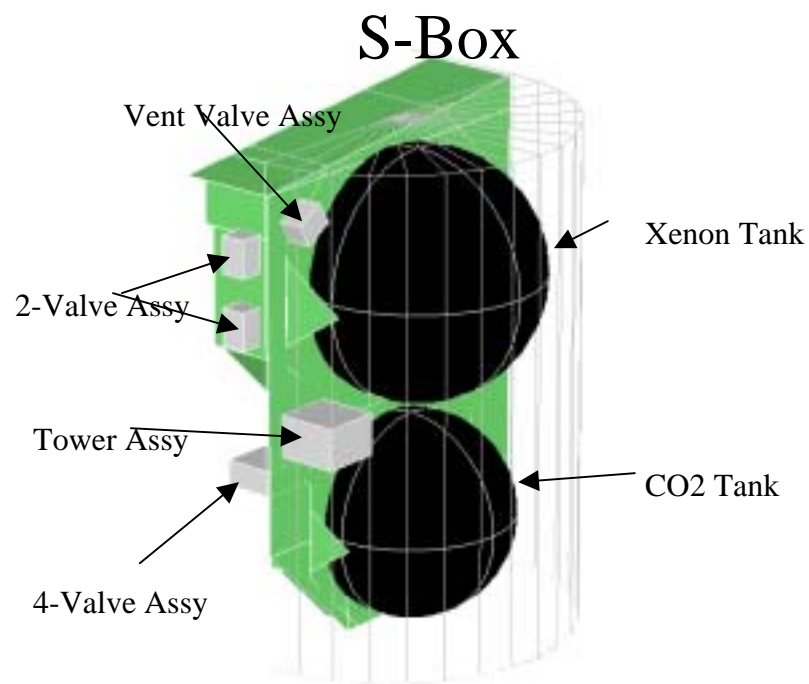
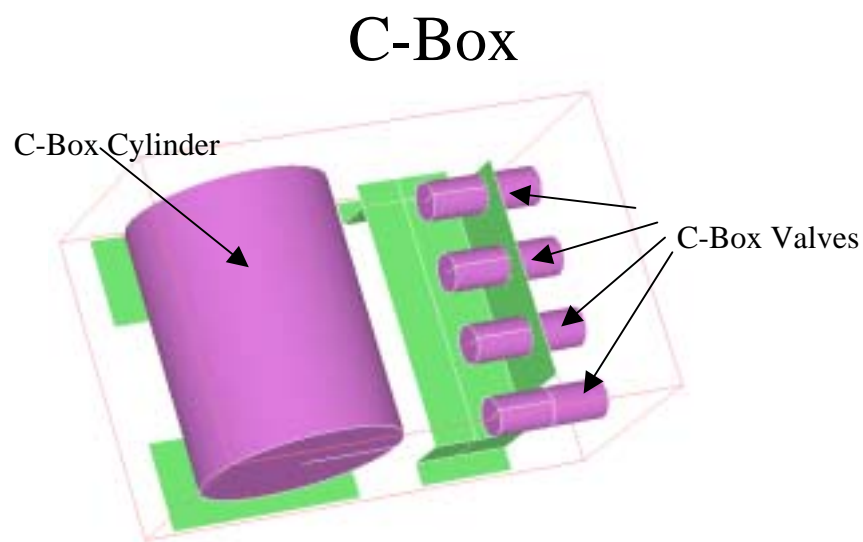
TRD Gas Supply

- 6 W dissipated in Supply (S) box and 4 W in Control (C) box
- Component Limits include:
 - Valves: +5°C to +55°C
 - CO₂ tank: +5°C (+33°C for measurement) to +65°C
 - Xe Tank: +5°C (+20°C for measurement) to +65°C
 - Pump: 0°C to +40°C



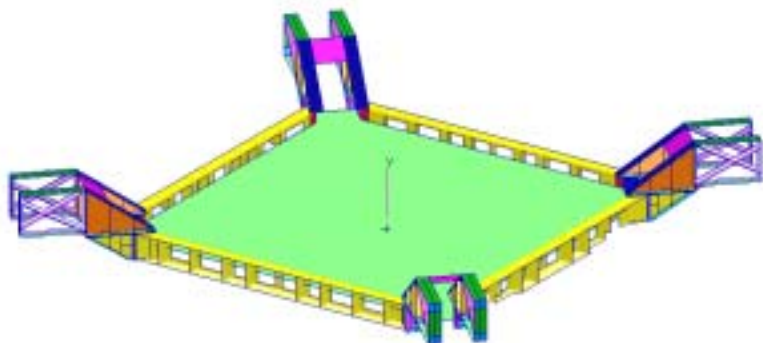
TRD Gas Supply

- MLI will enclose both “boxes”
- Dedicated heaters will maintain thermal limits
- Both boxes mounted to USS

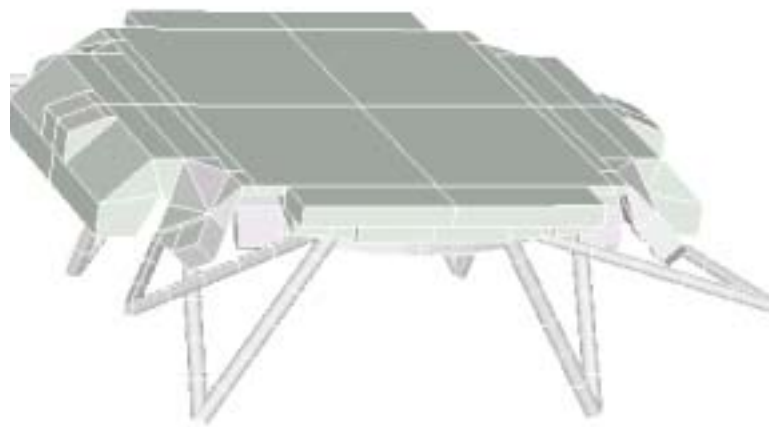


TOF

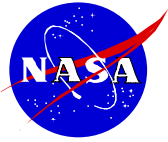
- Heat dissipation on PM's (3.2 W on Upper and 3.6 W Lower TOF)
- Limits: -20°C to +40°C Operating, -50°C to +50°C Non-Operating
- Upper TOF “lumped” with TRD
- Lower TOF PM boxes include radiators



Upper TOF Support



Lower TOF

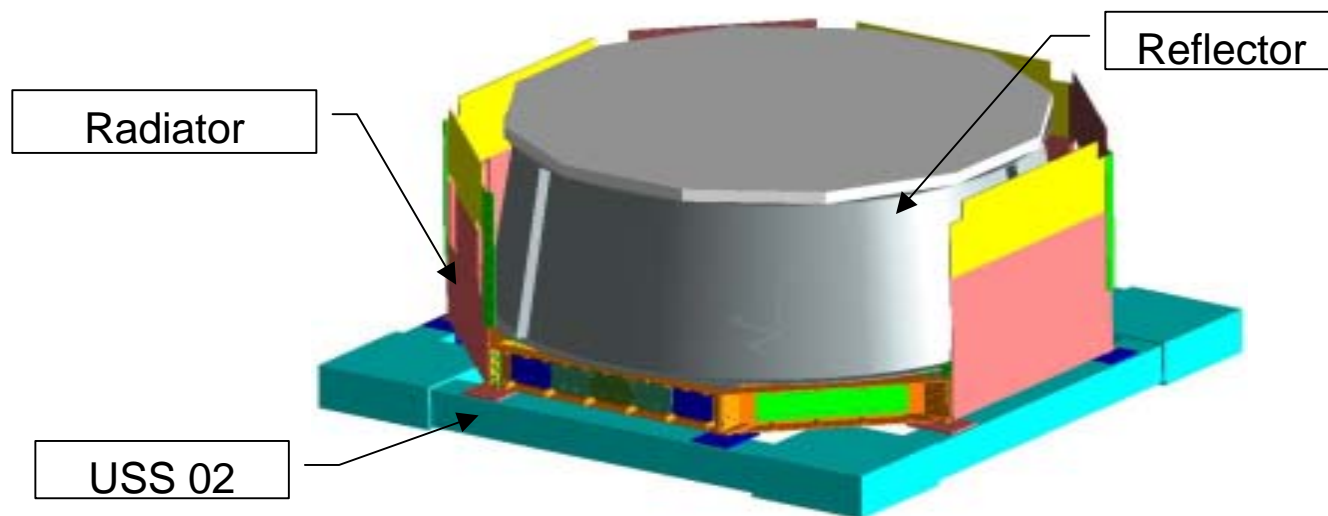


Anti-Coincidence Counter (ACC)

- **Almost identical to what was flown on AMS-01**
- **Limits: -20°C to +40°C Operating and Non-Operating**
- **Small heat dissipation (~1 watt) in Photo Multiplier Tubes (PMT's) mounted on VC conical flange.**
- **ACC support shell coated with low emissivity surface to minimize radiation from Tracker support shell.**

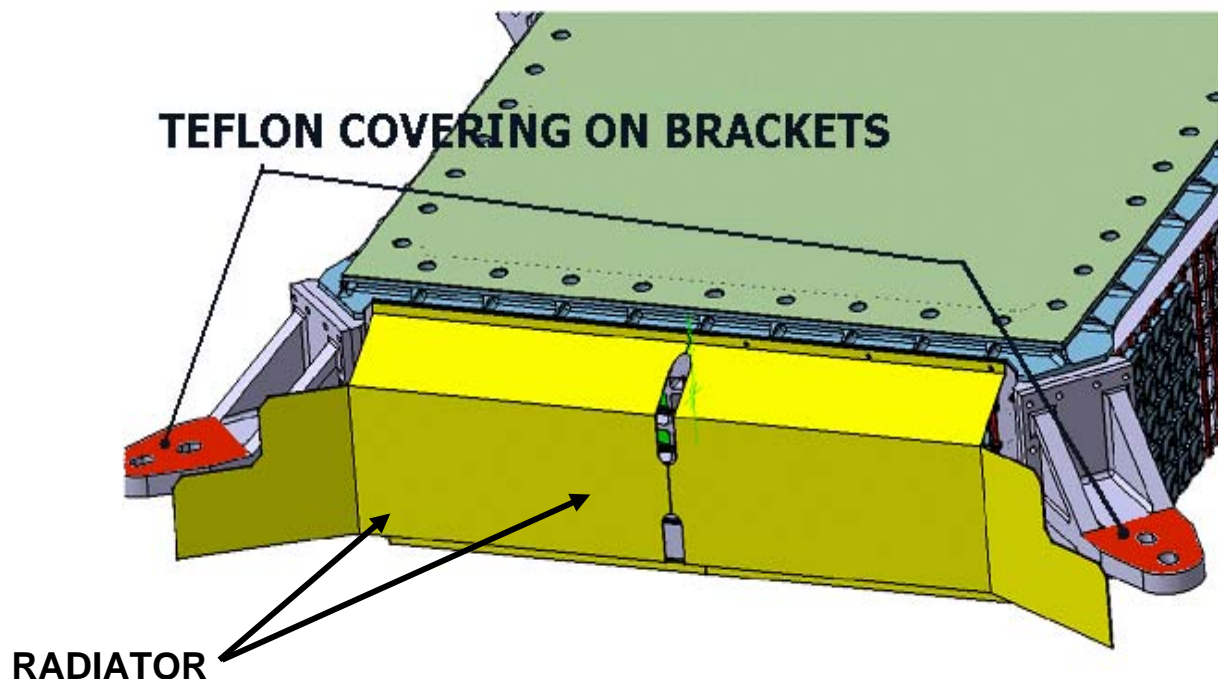
Ring Imaging Cherenkov Counter (RICH)

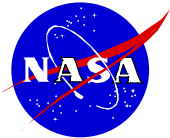
- Heat produced in 680 PMT's (17.7 W total) located at bottom of RICH. An additional 9.8 W is dissipated around octagonal structure. Heat is rejected by dedicated radiator along with some conduction to USS.
- Limits: -20°C to +40°C Operating, -40°C to +40°C Non-Operating
- RICH Reflector and backside of radiators will be covered with MLI blankets.



Electromagnetic Calorimeter (ECAL)

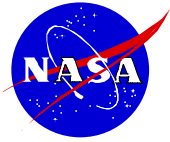
- ECAL heat (46 W) is rejected via a combination of direct radiation via “winglet” radiators and side panels.
- Limits: -20°C to +40°C Operating, -40°C to +40°C Non-Operating
- Bottom (-Z) of ECAL will be covered with MLI to minimize heat transfer to ISS.





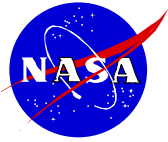
TRACKER

[See Tracker Thermal Control System Presentation](#)



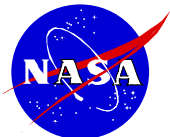
Thermal Control Hardware – MLI Blankets

- **All MLI blankets will meet NASA requirements for venting and grounding**
- **Known MLI blankets include:**
 - **Vacuum Case (+/- Y quadrants, conical flanges, upper and lower skirts)**
 - **USS-02 VC joints and Upper Trunnion Bridges**
 - **Cryo-coolers**
 - **Radiator backsides (Tracker, RAM, WAKE, RICH/ECAL)**
 - **TRD sides and below Zenith radiator**
 - **RICH reflector and backside of RICH radiators**
 - **Between TOF and Tracker (upper and lower)**
 - **Between RICH and ECAL**
 - **ECAL bottom**
 - **TRD Gas System boxes C and S**
 - **Uninterruptible Power Supply (UPS)**
 - **Cryomagnet Avionics Box (CAB)**



Thermal Control Hardware - Heaters

- **There will be various thermostatically controlled heaters on the AMS-02 payload.**
- **Most heaters will be disabled as experiment electronics are powered.**
- **Final heater sizes and set points still need to be confirmed.**



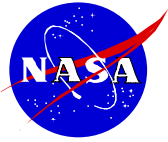
Thermal Control Hardware – Heaters (continued)

HEATER LINES		A [W]	B [W]
	PDS	150	150
1	Ram Tracker Radiator	50	50
2	Ram main radiator	210	210
3	Ram Rich/Ecal crates radiator	30	30
4	Wake Tracker Radiator	50	50
5	Wake main radiator	250	250
6	Wake Rich/Ecal crates radiator	30	30
7-10	Cryocoolers	250	250
11	TRD Gas Box	50	50
12	Tracker Thermal Control System	100	100
	TOT	1170	1170



THERMAL ANALYSES

- **AMS-02 Thermal model integrated with ISS Assembly Complete model**
- **Thermal analysis survey performed for 259 ISS attitudes (37 combinations of YPR for 7 different beta angles) to cover the ISS attitude envelope both with and without the orbiter docked.**
- **Additional detailed analyses performed for worst case attitudes**
- **Magnet charging/discharging analyses**
- **Active radiation surface assessment**
- **Specular surfaces identified**



PENDING THERMAL ANALYSES

- **Launch-to-activation (LTA) analysis of AMS-02 in payload bay**
- **Analysis of transfer from STS to ISS**
- **EVA touch temperature analyses (as required)**
- **“Failed On” heater analyses**
- **Auto-ignition assessment**
- **Stuck open vent door**
- **Evaluation of NASA Integration hardware (PVGf, BCS Camera, etc.)**



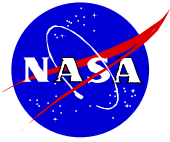
THERMAL RESULTS

- **Thermal models are still being refined.**
- **No thermal concerns for NASA hardware.**
- **VC On-Orbit Temperature Predictions:**
 - Instantaneous (all surfaces): -55°C to +45°C (-67°F to +113°F)**
 - Orbit average (VC average): -27°C to +12°C (-17°F to +54°F)**
- **USS On-Orbit Temperature Predictions:**
 - All surfaces (except blankets): -64°C to +55°C (-84°F to +131°F)**
 - Capture bar: -18°C to +40°C (0°F to +104°F)**
 - VC Interface Joints: -34°C to +46°C (-30°F to +115°F)**



THERMAL RESULTS (continued)

- **Sub-detector temperature predictions are provided by CGS.**
- **Analyses show some sub-detector temperature violations (mission success) at extreme ISS environments.**
- **Thermal design and analysis are still being optimized and there are no show stoppers identified.**

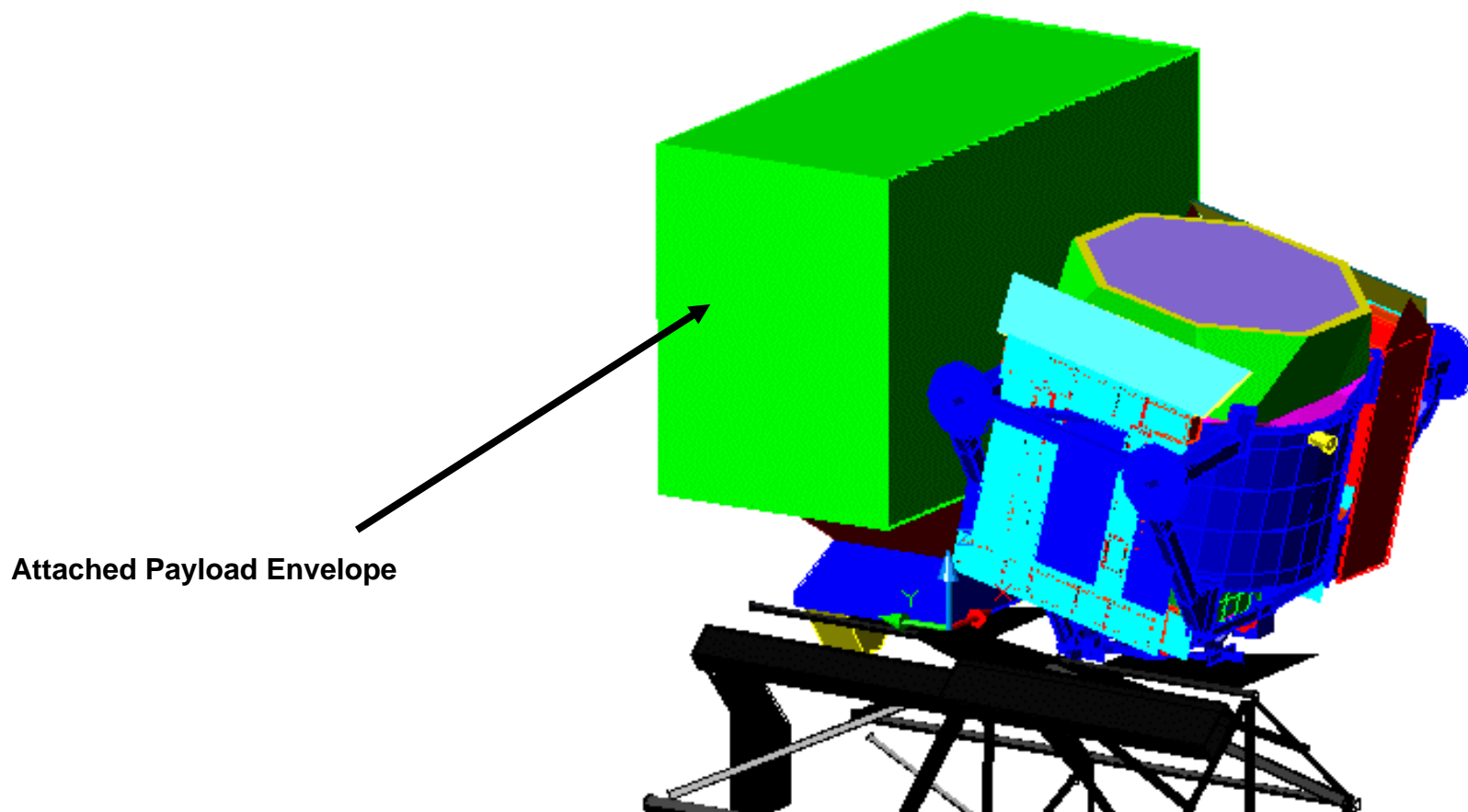


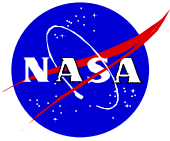
THERMAL RESULTS (continued)

	Minimum	Maximum	Comment
	°C	°C	
Main Radiators	-40.5	+30	
Crates	-17.2	+51.8	
Tracker Radiators	-72.7	+8.5	Active Loop Set Point temperature = -5°C to +15°C
RICH	-14.5	+39.7	
ECAL	-10.3	+37.3	
RICH/ECAL Crate Radiators	-19	+51.1	radiator optical properties may be improved
RICH/ECAL Crates	-12.5	+60.5	interface conduction improvements being investigated
TRD	-6	+38.5	TRD may be switched off at extreme hot conditions
TRD Gas System	-15	+40.4	heaters will control low temperature extremes
Cryo-Cooler Radiator	-53.8**	+11.8	** -30°C with operating LHP
CAB	-15.3	+45.0	

Verification of Requirements

- **Active Radiation Surface Assessment to satisfy SSP 57003 section 3.4.1.1.6.A (view factor from radiators to attached payload envelope)**

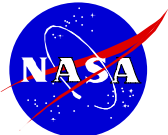




Verification of Requirements

- **View Factors (VF) from each AMS-02 radiator to Attached Payload Envelope (requirement is <0.1)**

Active surfaces	VF
Main radiator RAM	0.041
Main radiator WAKE	0.011
R&E Crate Radiator RAM	0.03
R&E Crate Radiator WAKE	0.015
Tracker radiator RAM	0.042
Tracker radiator WAKE	0.021
Zenith Radiator	0.021
RICH radiators	0.109
ECAL radiators	0.03
CAB radiator	0.009



Verification of Requirements

- **Specular Surface Identification (per ISS 57003 3.4.1.1.5 and 3.4.1.1.6.B)**

Specular surfaces	Surface Material	Specularity	VF to APE
R&E Crate Radiator RAM	Silver Teflon (5 mil FEP)	>90%	0.03
R&E Crate Radiator WAKE	Silver Teflon (5 mil FEP)	>90%	0.015
ECAL radiators	Silver Teflon (5 mil FEP)	>90%	0.03
CAB radiator	Silver Teflon (5 mil FEP)	>90%	0.009
Vacuum Case (+/-X quadrants)	Silver Teflon (5 mil FEP)	>90%	0.381



Needed to Verify Requirements

- **A simplified AMS-02 thermal model will be provided to the ISS and STS Programs.**
- **Integrated analysis will be performed to verify that active radiation surfaces with $VF > 0.1$ to APE do not adversely affect the operation of other Attached Payloads.**
- **Integrated analysis will also be performed to verify that specular surfaces do not adversely affect the operation of other Attached Payloads.**



Input for Payload ICD

- **AMS-02 to PAS Interface temperature extremes will be provided.**
- **A drawing will be provided showing AMS-02 external surface optical nodes.**
- **A table will be provided indicating external optical surface properties (absorptivity and emissivity) for all significant surfaces.**



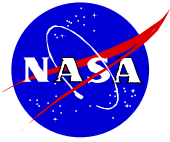
COMPONENT/SUB-DETECTOR TESTING

- **Thermal Tests to Date**
 - TTCS “bread board model” (thermal)
 - Thermal bars (T/V)
 - TRD Module (T/V)
 - TOF PMT’s (T/V)
 - RICH PMT mounting (T/V)
 - ECAL PMT mounting (T/V)
 - ECAL “pancake” thermal properties characterization
 - Crate Qualification tests (T/V Cycling, Thermal Balance)
 - Cryo-coolers (performance)



COMPONENT/SUB-DETECTOR TESTING

- **Planned Thermal Tests**
 - PAS Interface (thermal at -120 F and +200 F)
 - Crate (acceptance T/V Cycling)
 - TOF (proto-flight T/V)
 - ECAL (proto-flight T/V)
 - RICH (proto-flight T/V)
 - TRD Gas System (T/V)
 - TRD Front End Electronics (T/V)
 - CAB (T/V)
 - TTCS pumps (T/V)
 - ACC PMT (T/V)
 - Cryo-cooler (T/V)
 - Warm He valves (T/V)
 - UPS (T/V)



INTEGRATED T/V TESTING

- **Integrated Thermal-Vacuum test will be performed on the entire AMS-02 Payload**
 - **AMS-02 operated at various thermal environments and power levels**
 - **First opportunity for some components to operate in vacuum**
 - **Functional checks performed before, during and after**
 - **Verify thermal interfaces**
 - **Verify performance of selected thermal control hardware**